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Adler et al.

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(54) **DYNAMICALLY RELOCATABLE TILEABLE DISPLAYS**

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(52) U.S. Cl. **345/1.3; 345/903**

(58) Field of Search **345/156-179, 345/1, 903, 1.3; 178/18-19**

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Primary Examiner—Jeffery Brier

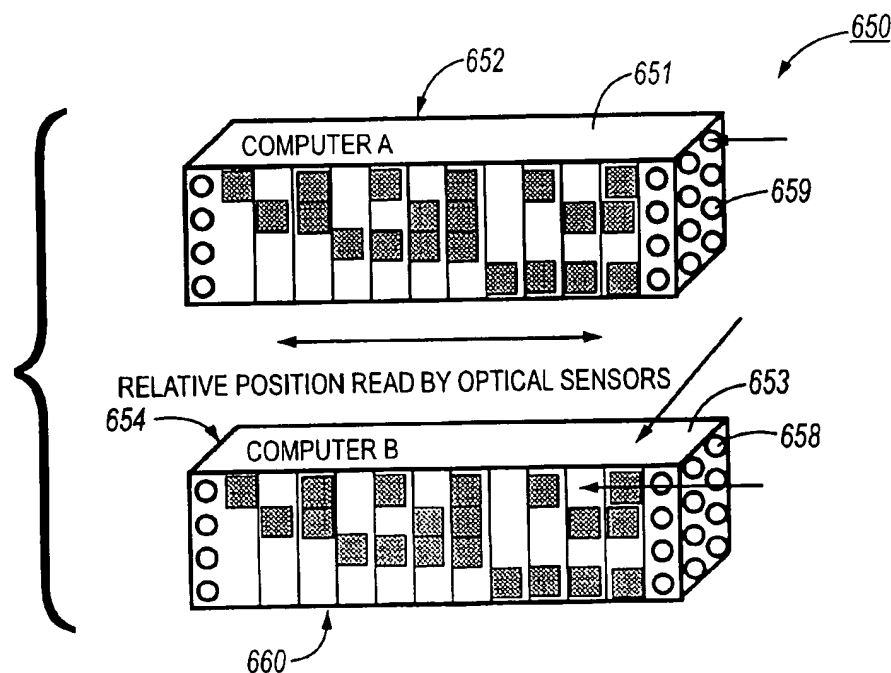
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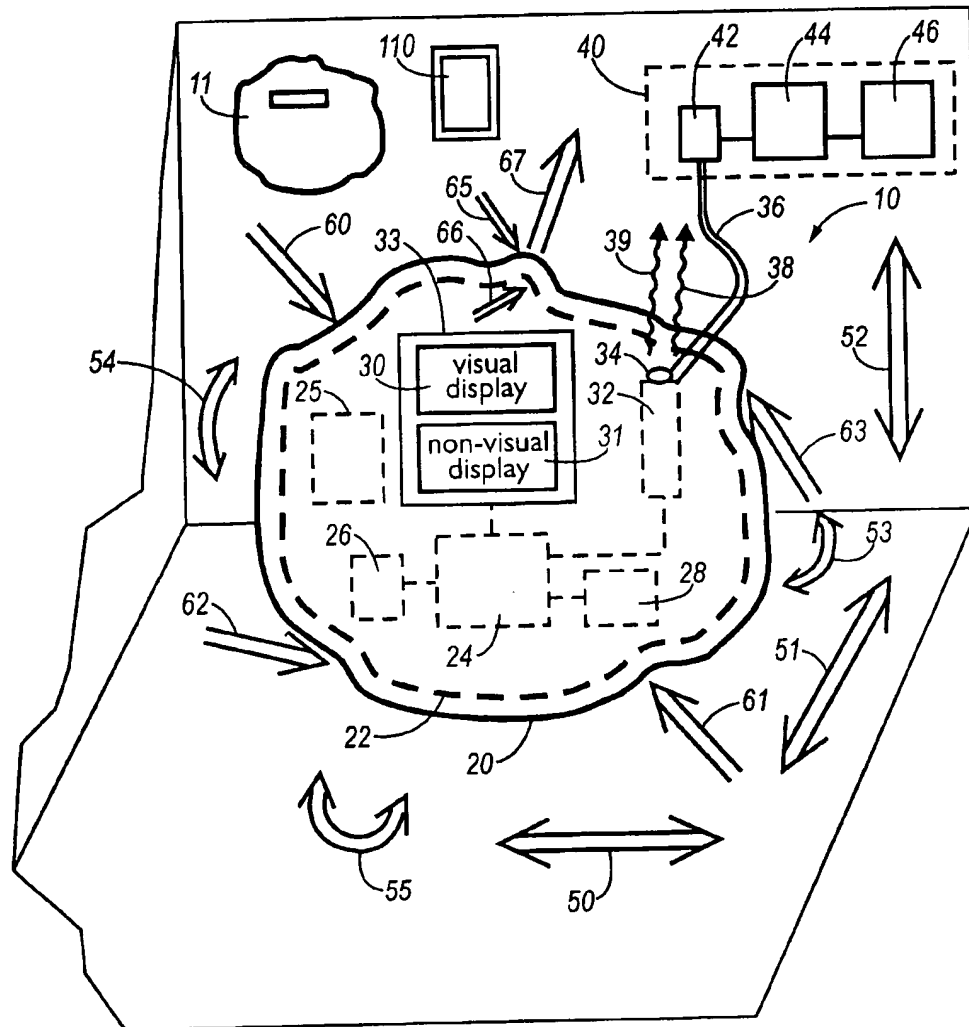
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(57) **ABSTRACT**

A tileable computer display includes a first device having a processor and a display maintainable in communication with a second device having a processor and a display. Specific data to be displayed on both devices is based on respective spatial positions of the first device and second device relative to each other. Communication links can be through radio, optical, or physical interconnects.

16 Claims, 27 Drawing Sheets



*Fig. 1*

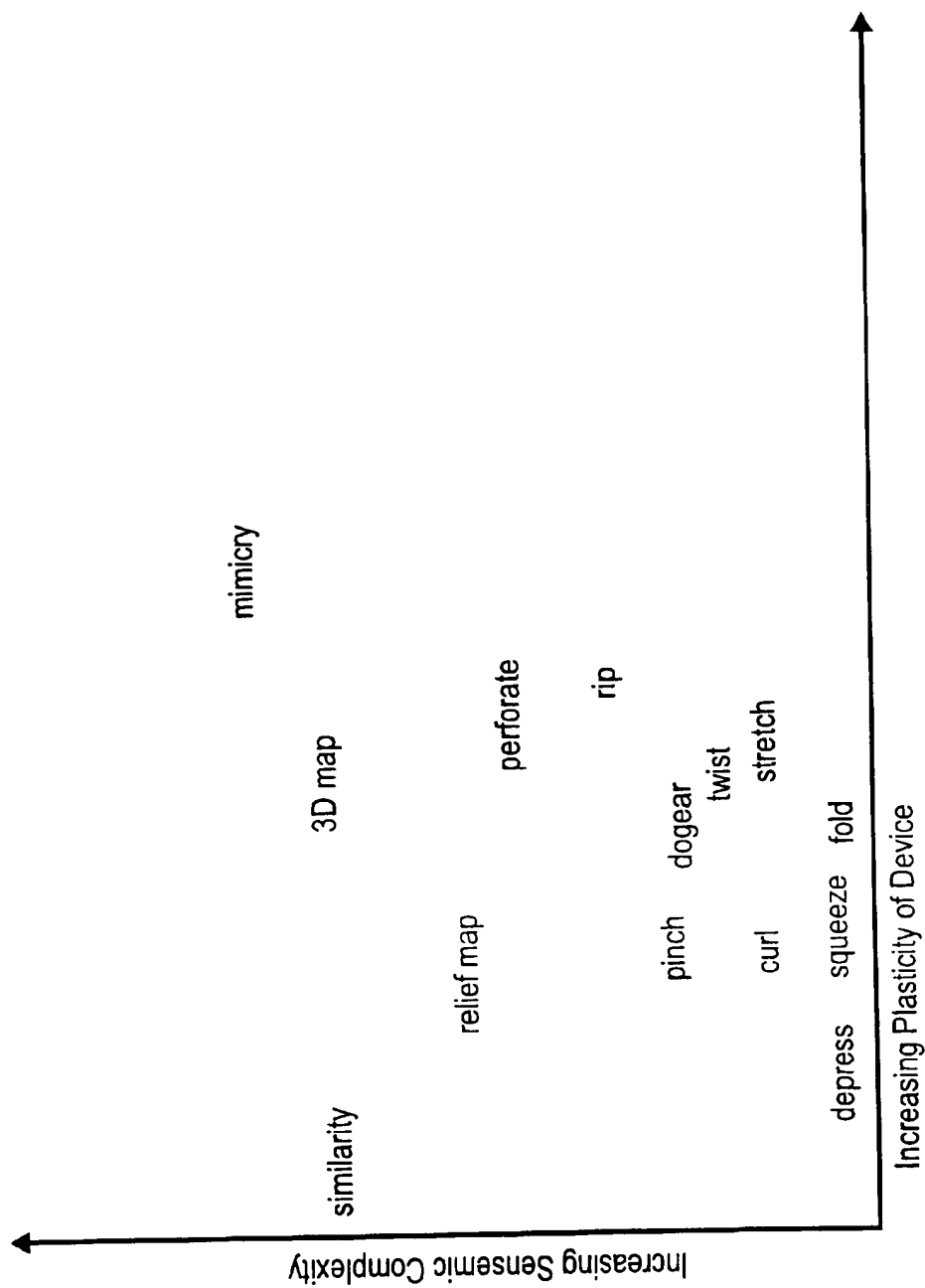


Fig. 2

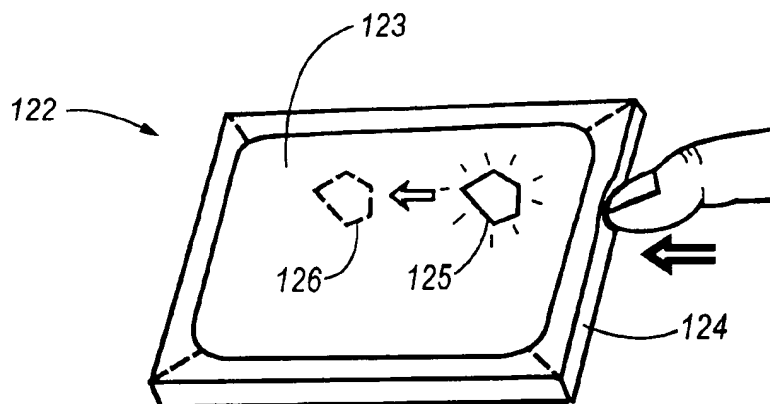


Fig. 3

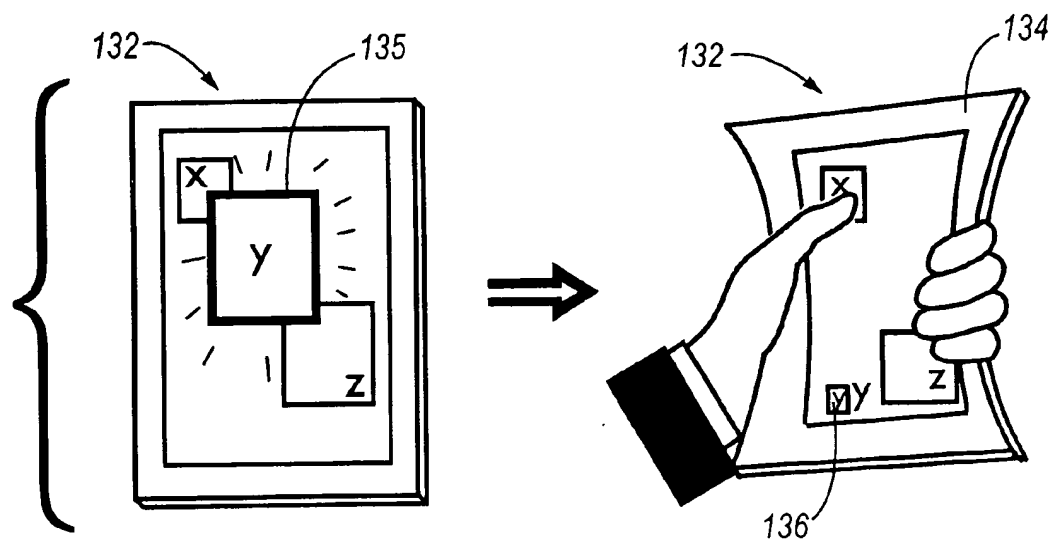


Fig. 4

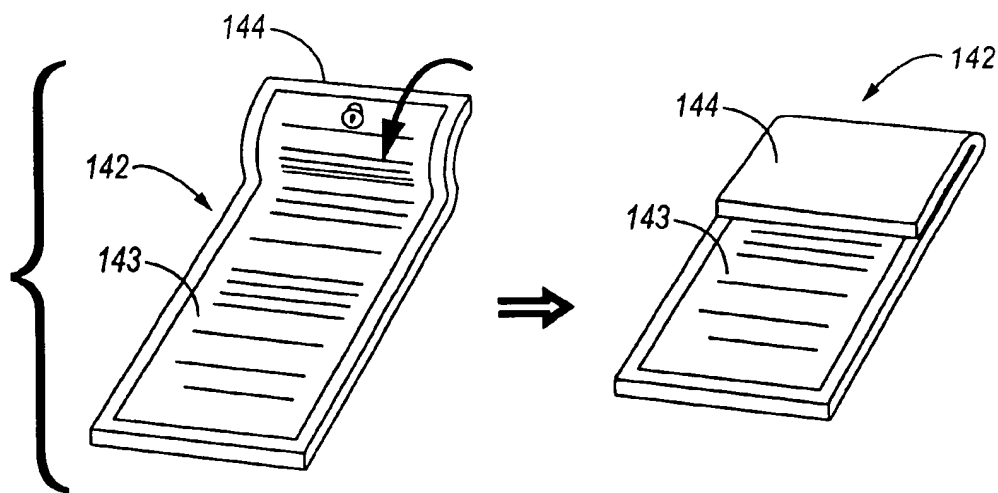


Fig. 5

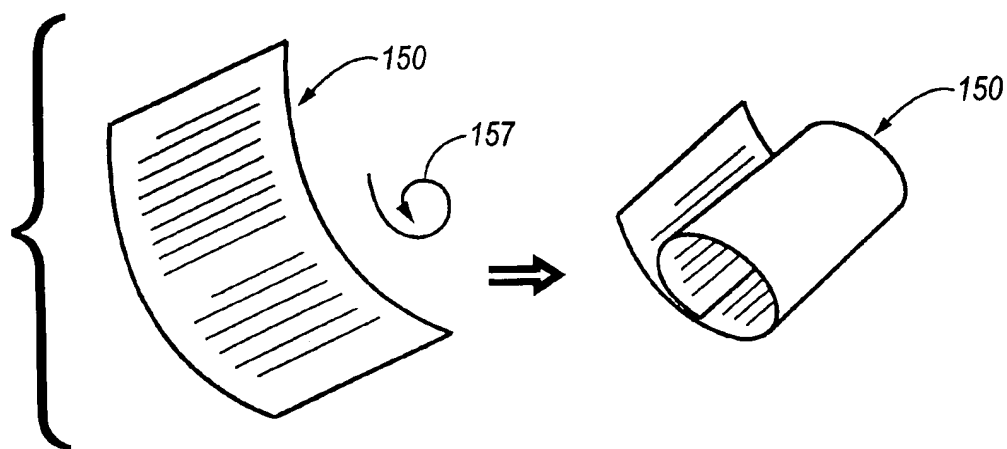


Fig. 6

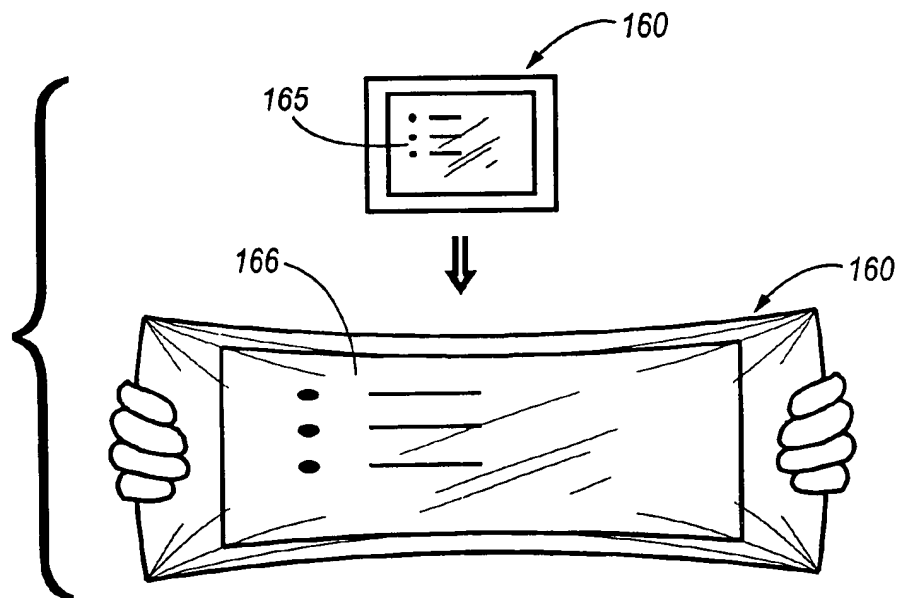


Fig. 7

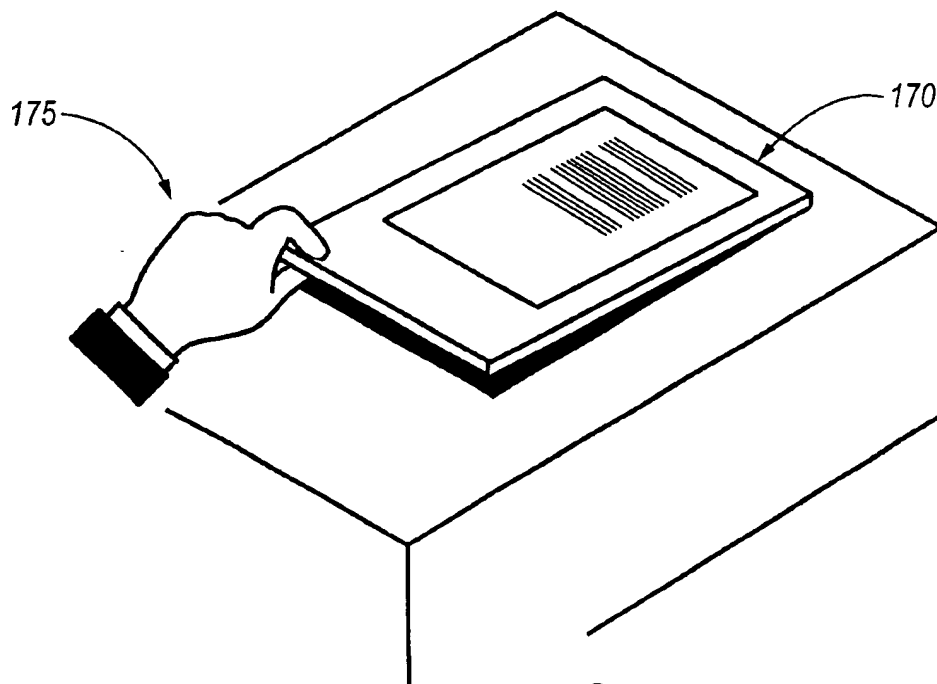
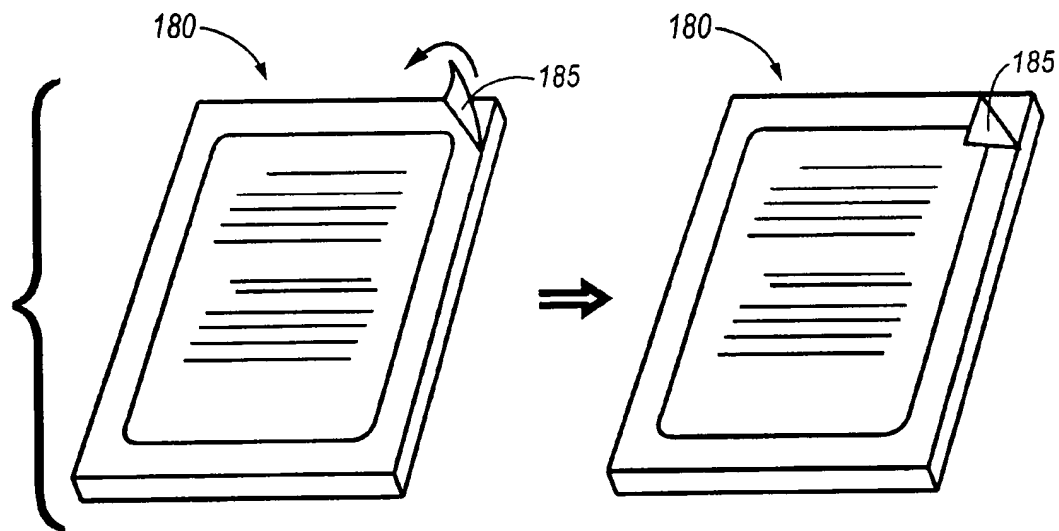
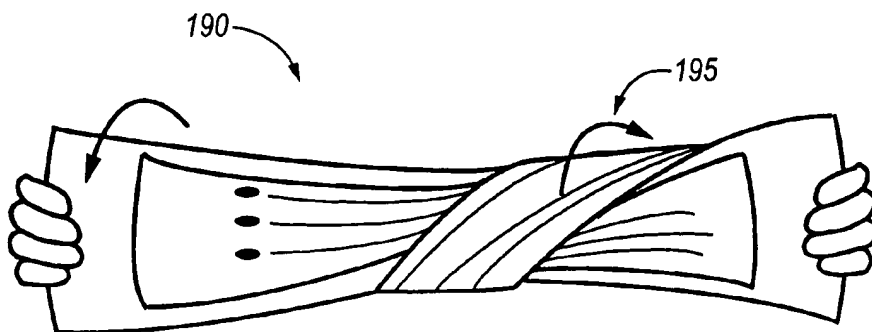


Fig. 8

*Fig. 9**Fig. 10*

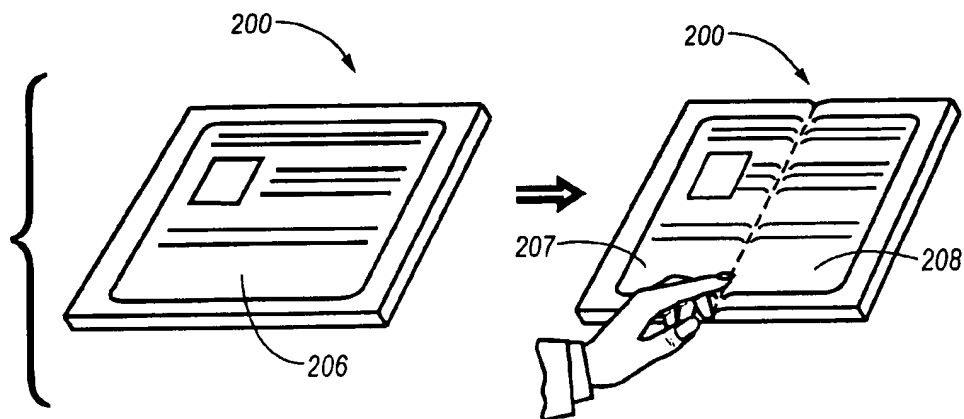


Fig. 11

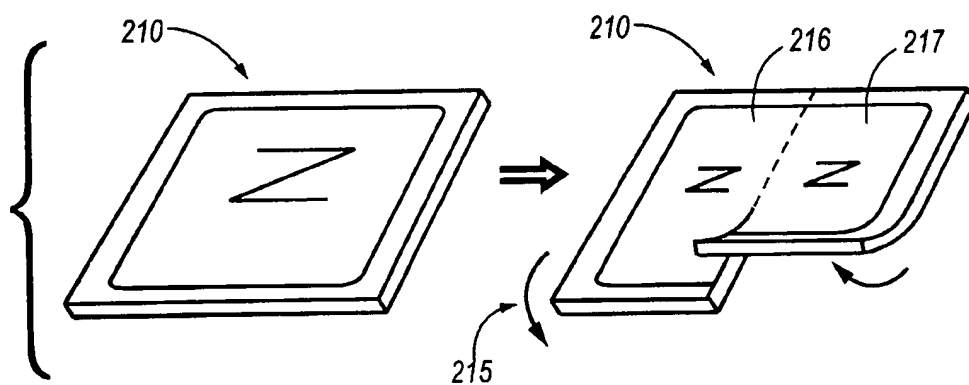


Fig. 12

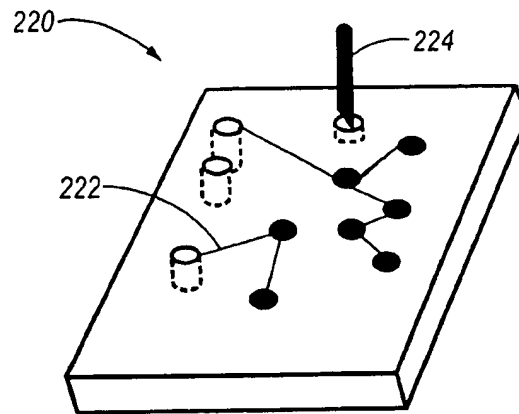


Fig. 13

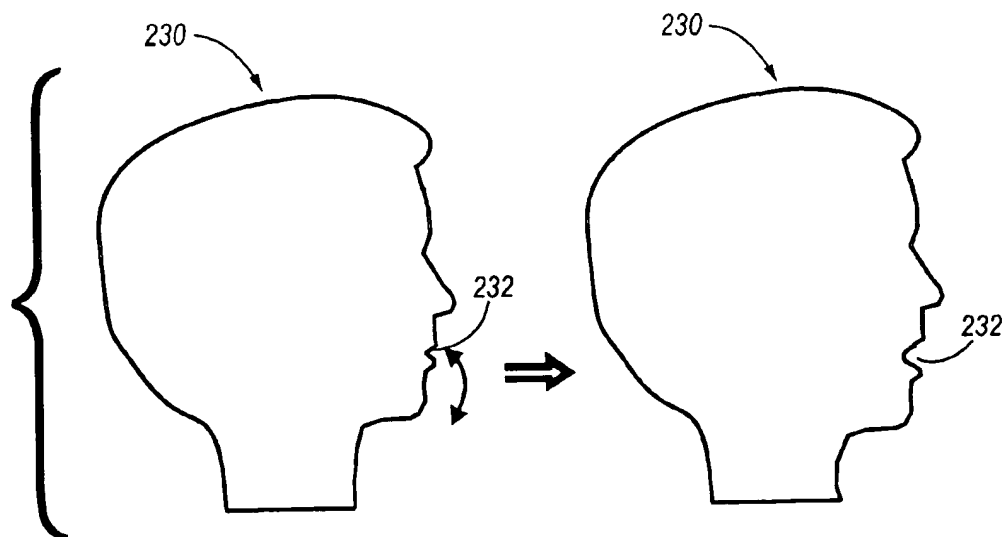


Fig. 14

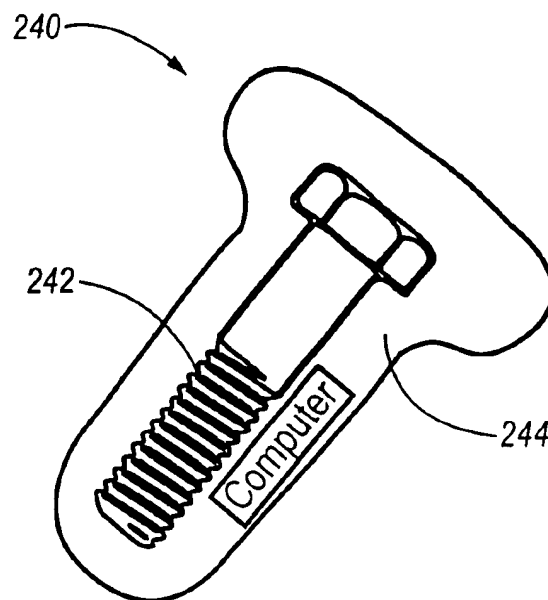


Fig. 15

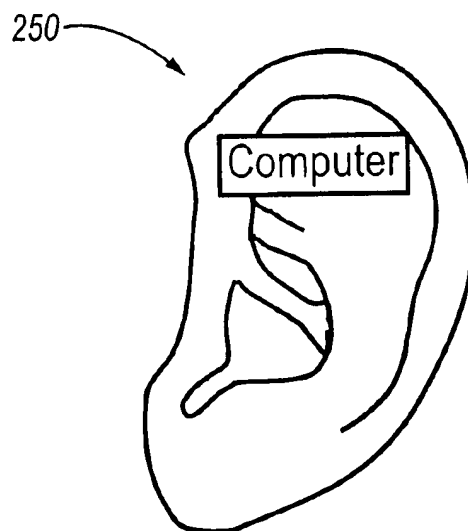


Fig. 16

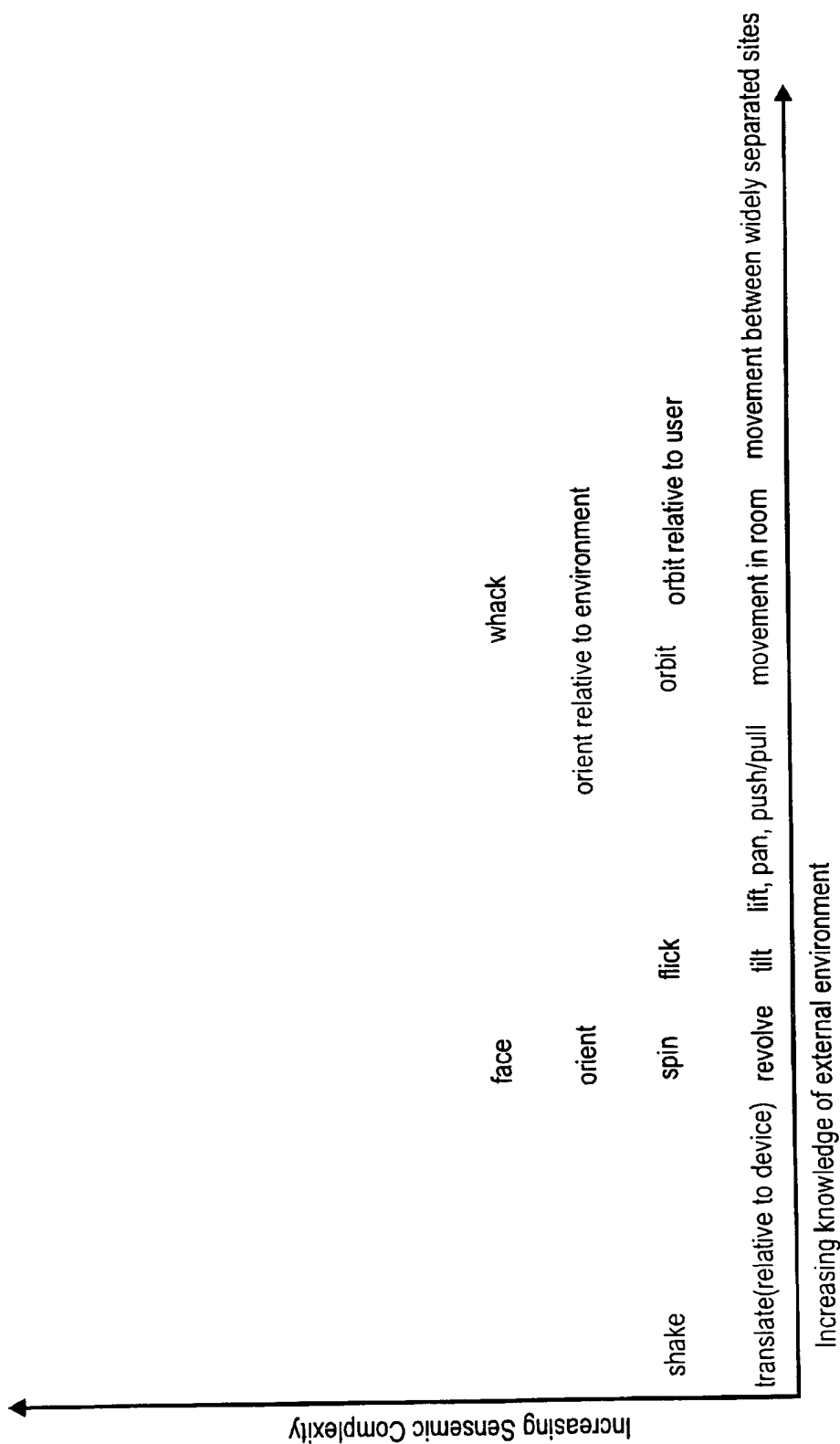


Fig. 17

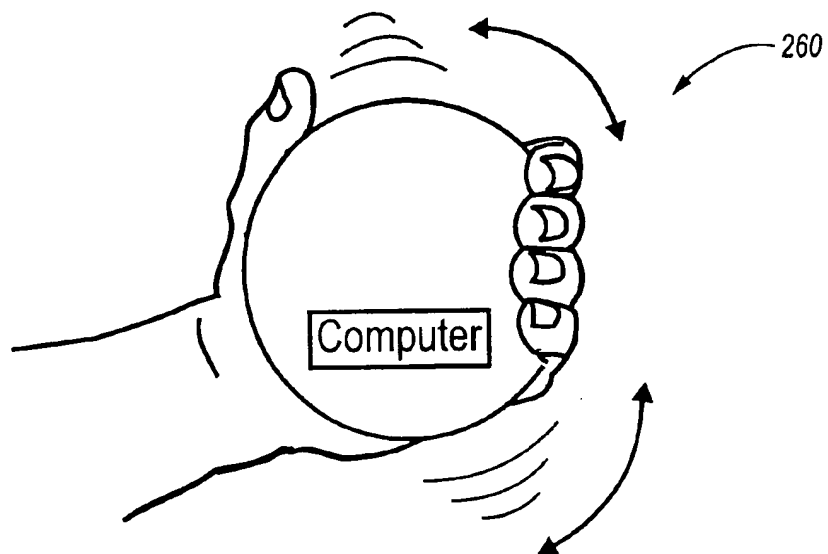


Fig. 18

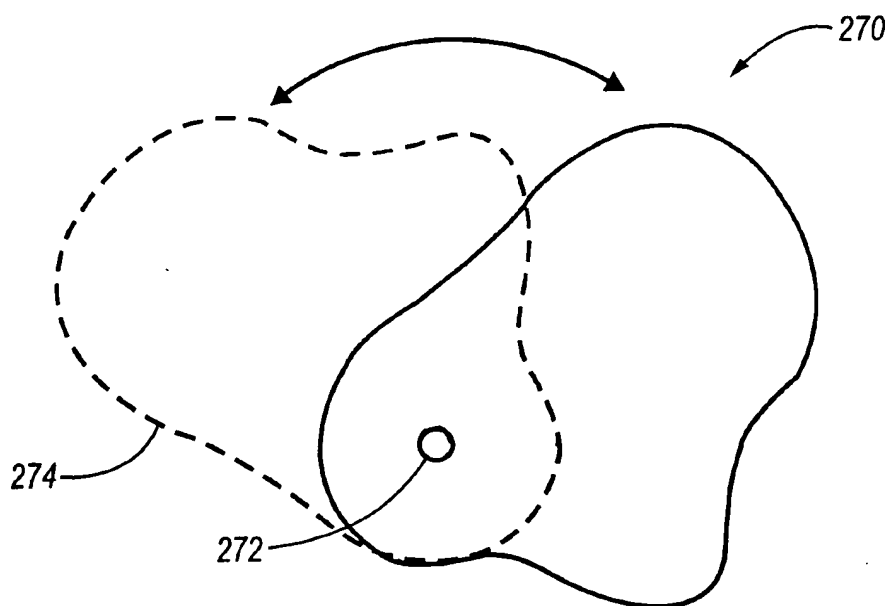


Fig. 19

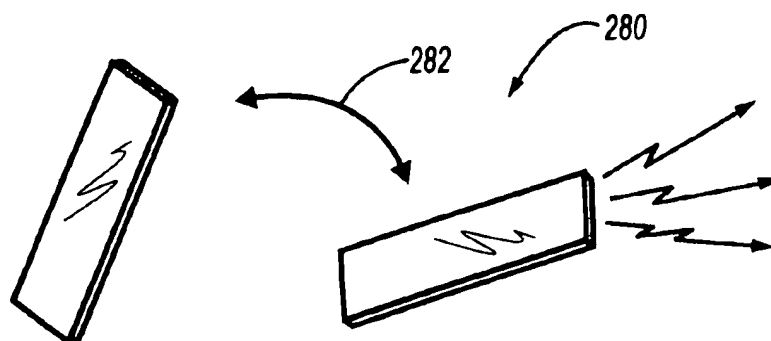


Fig. 20

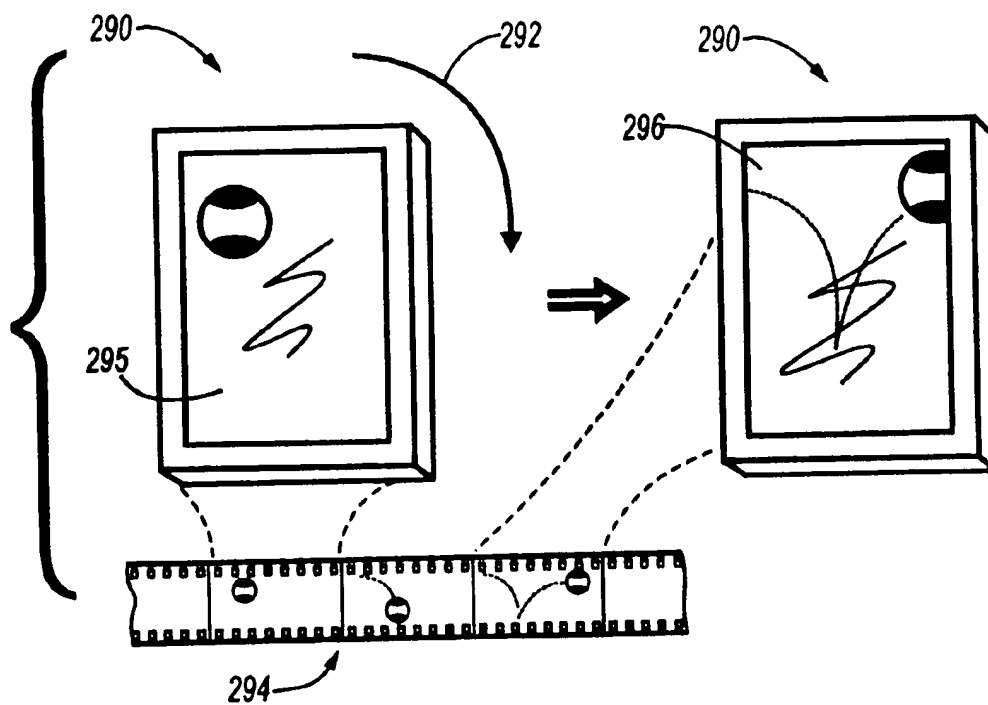


Fig. 21

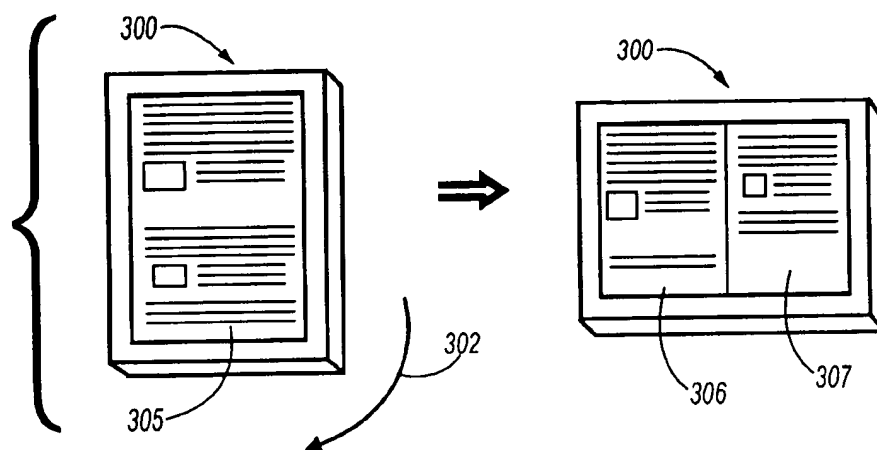


Fig. 22

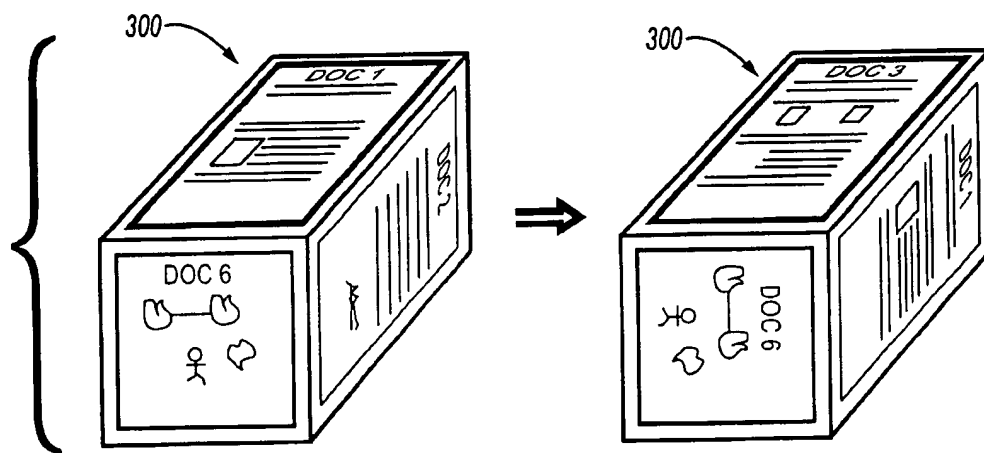


Fig. 23

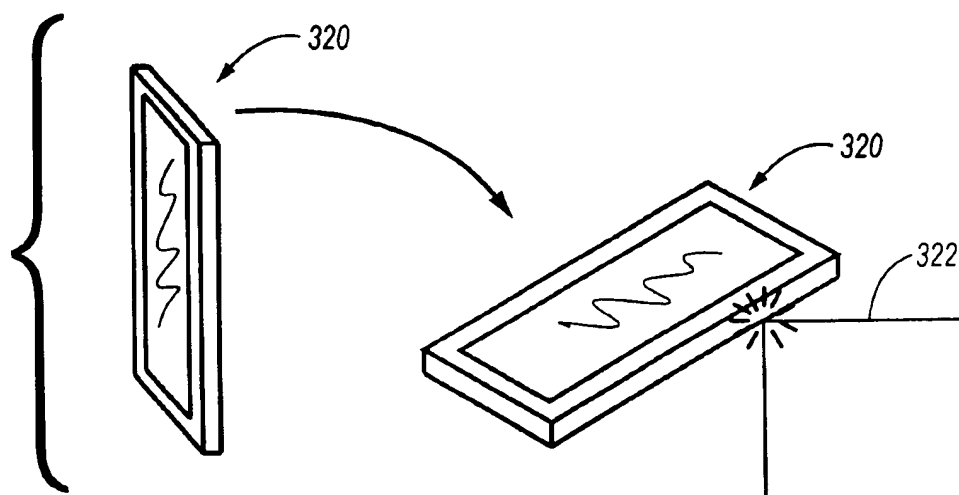


Fig. 24

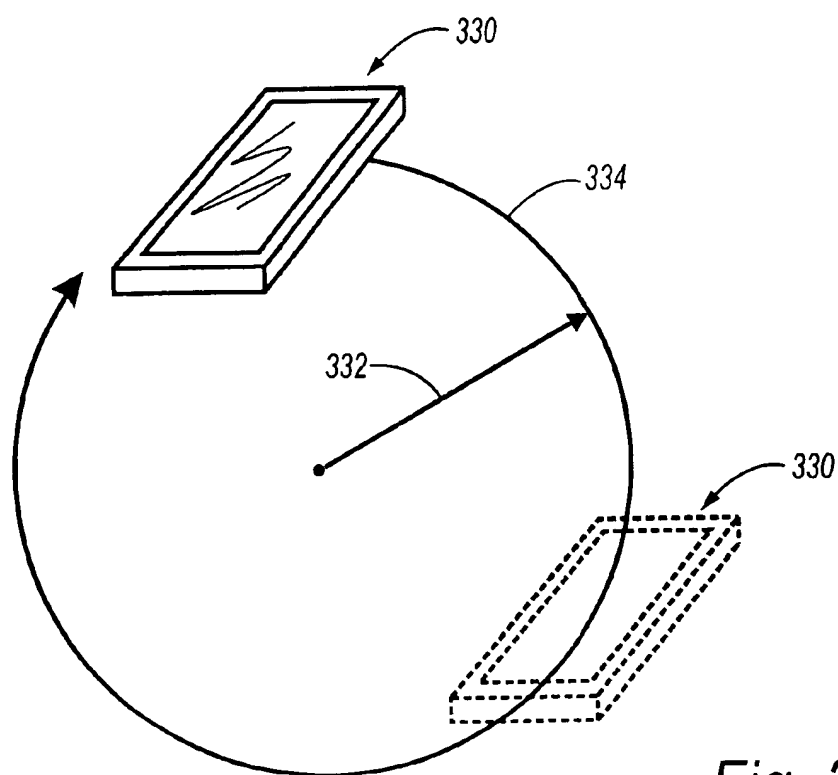


Fig. 25

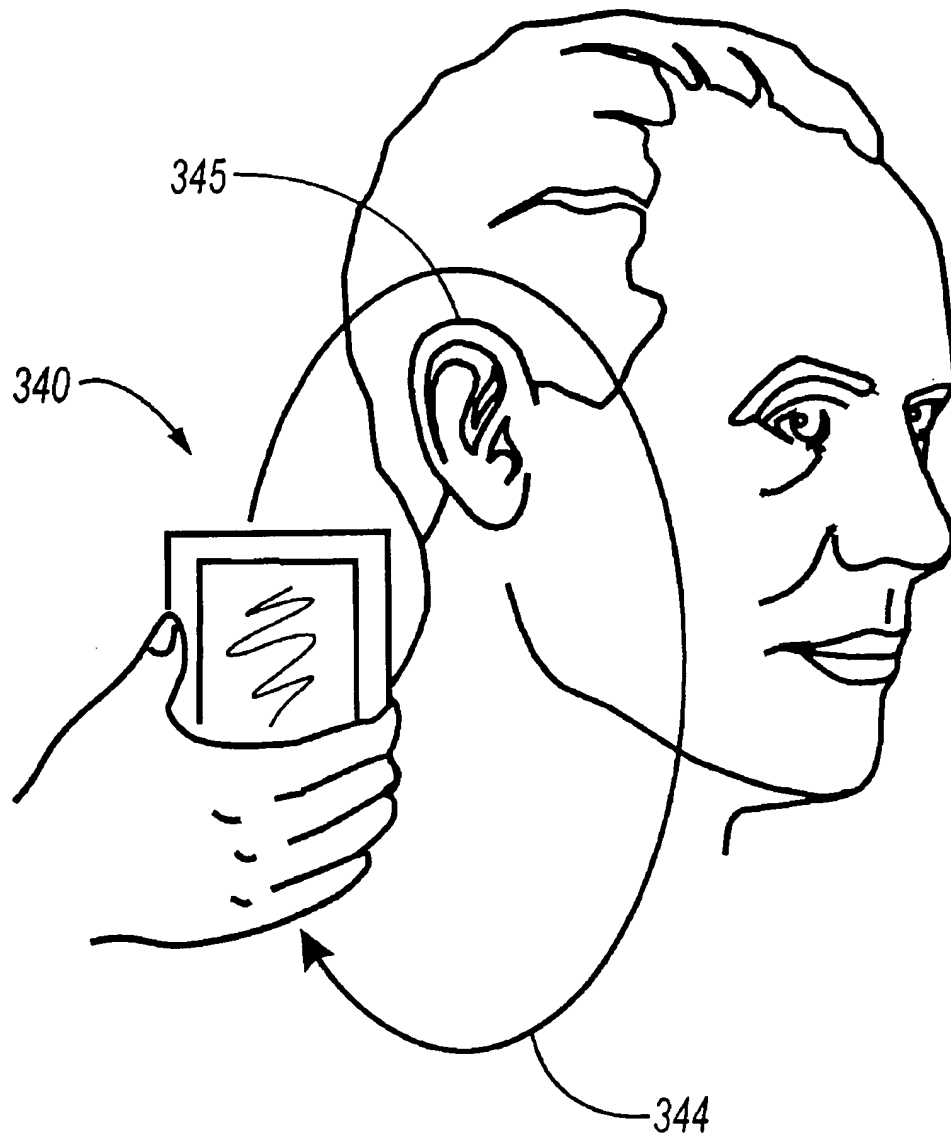


Fig. 26

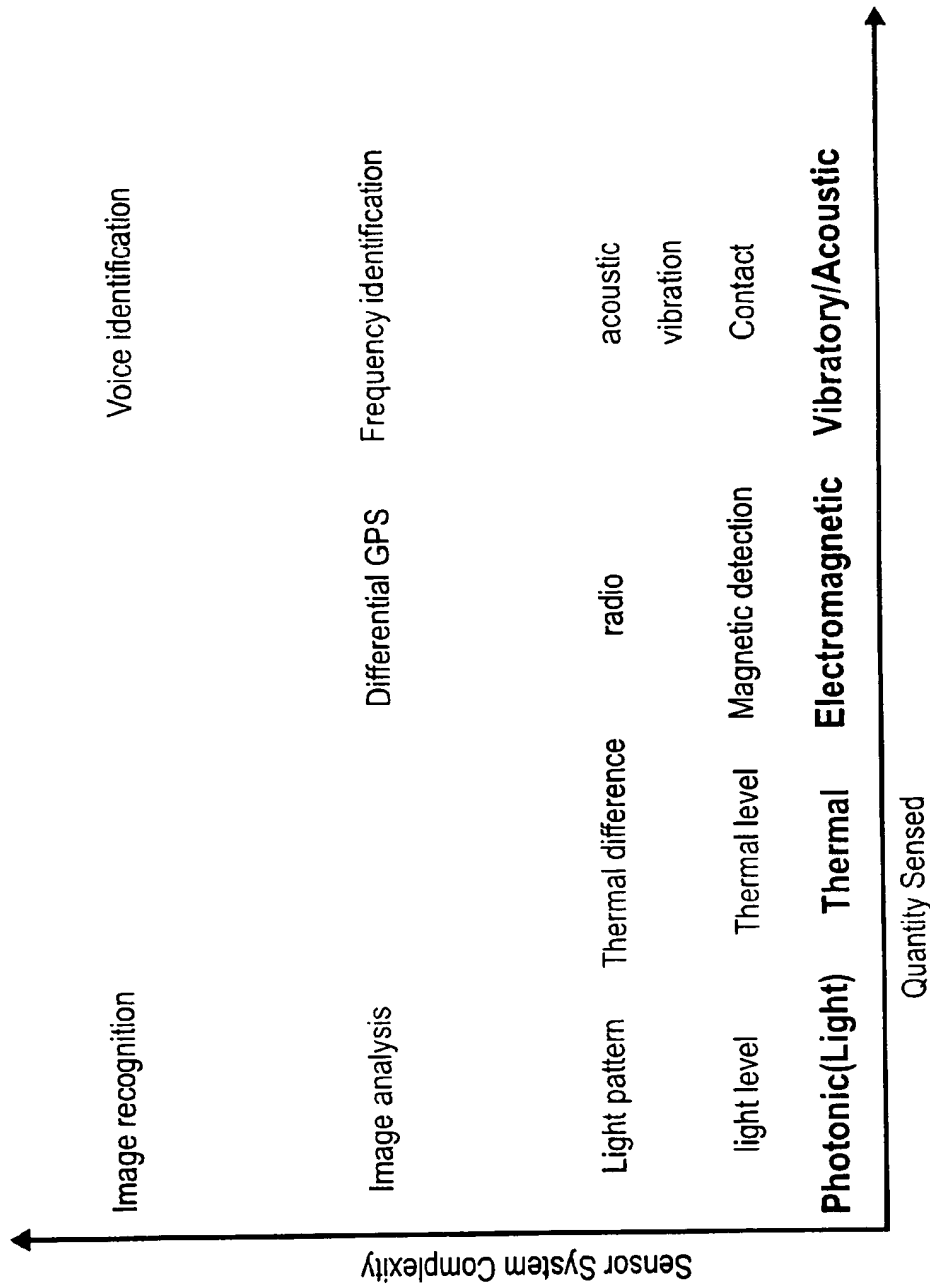


Fig. 27

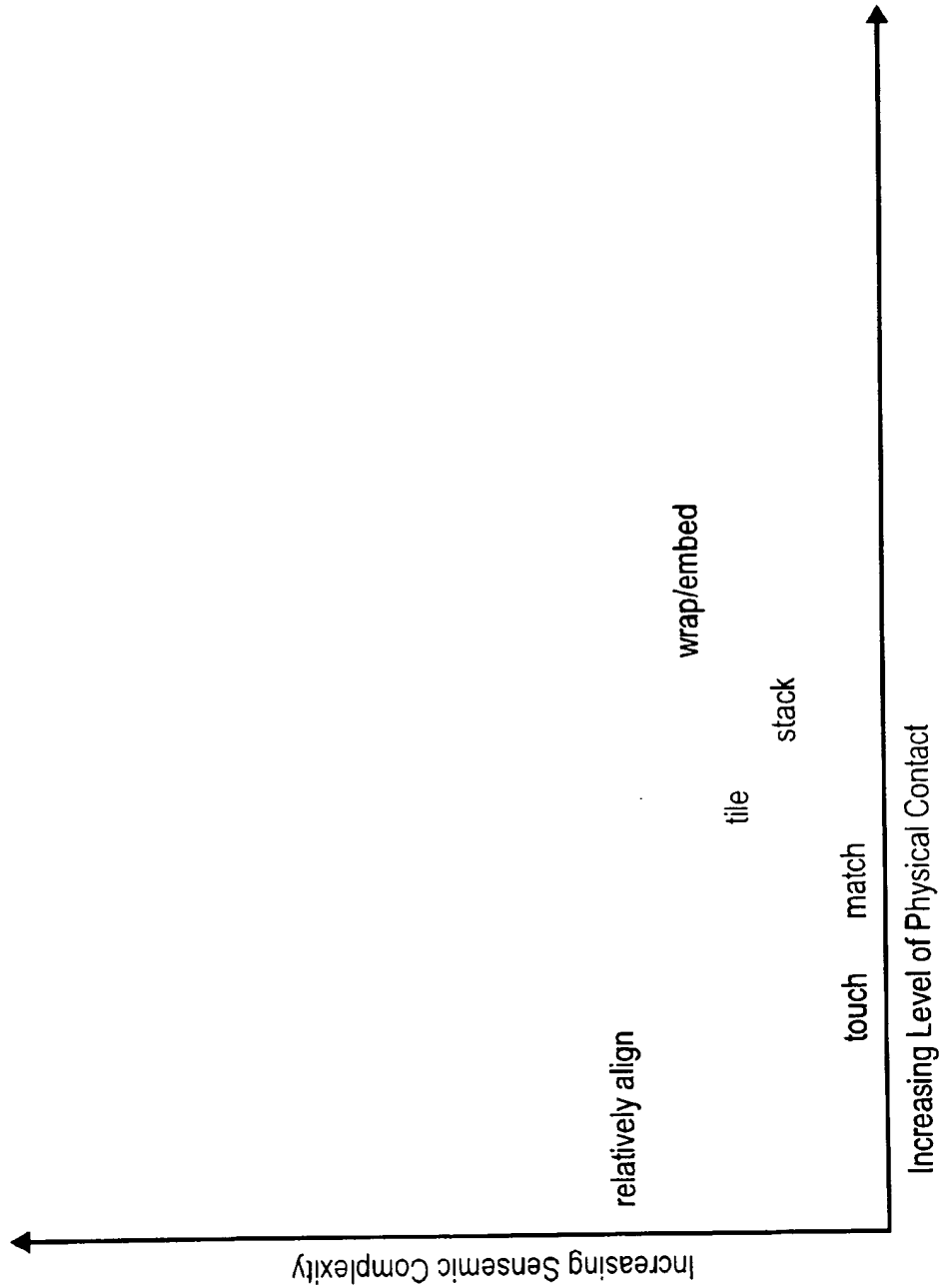
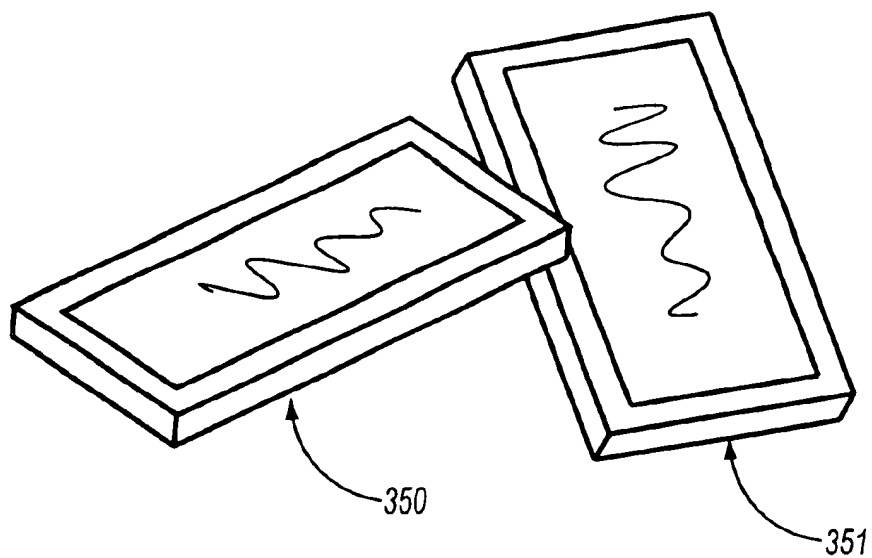
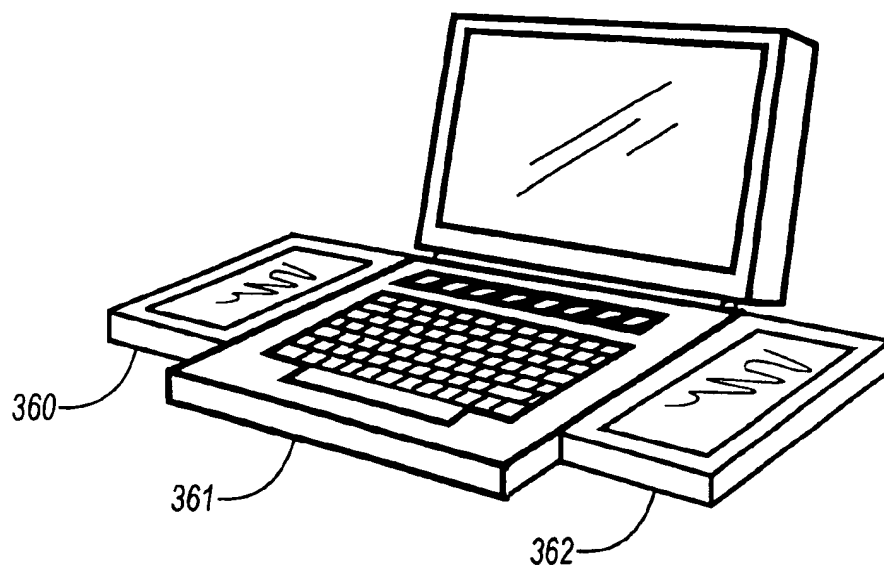
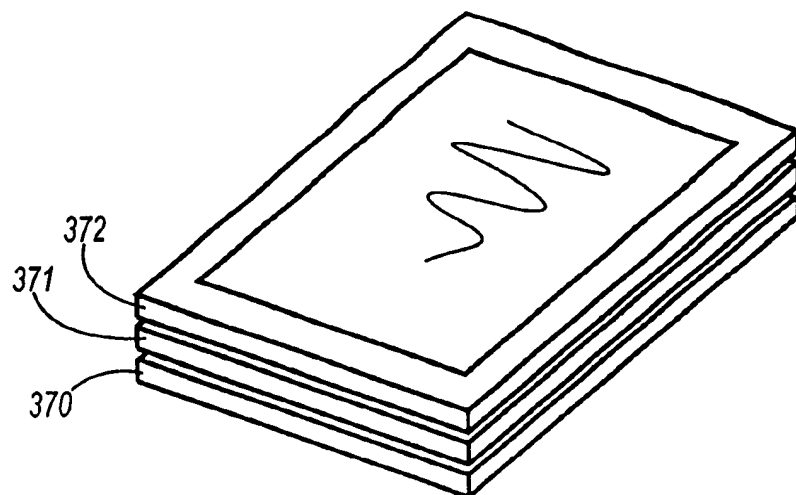
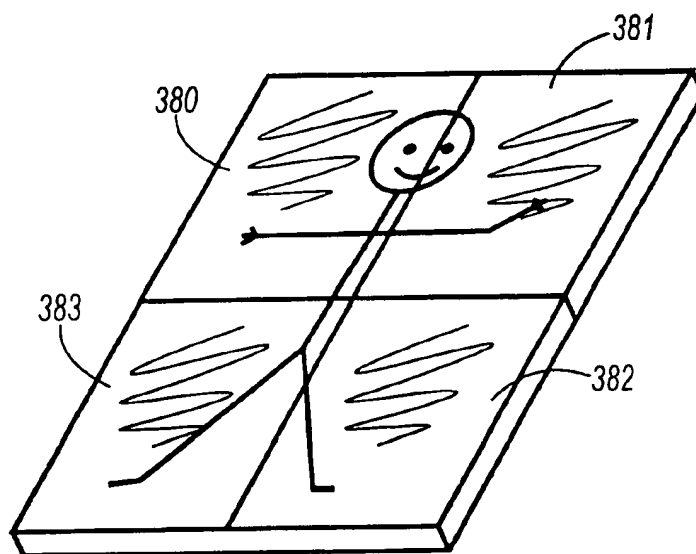
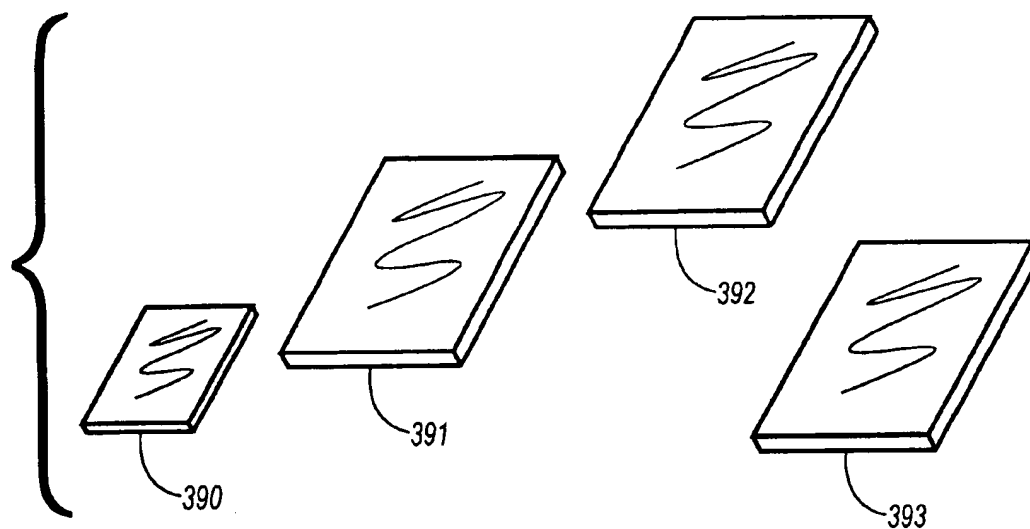
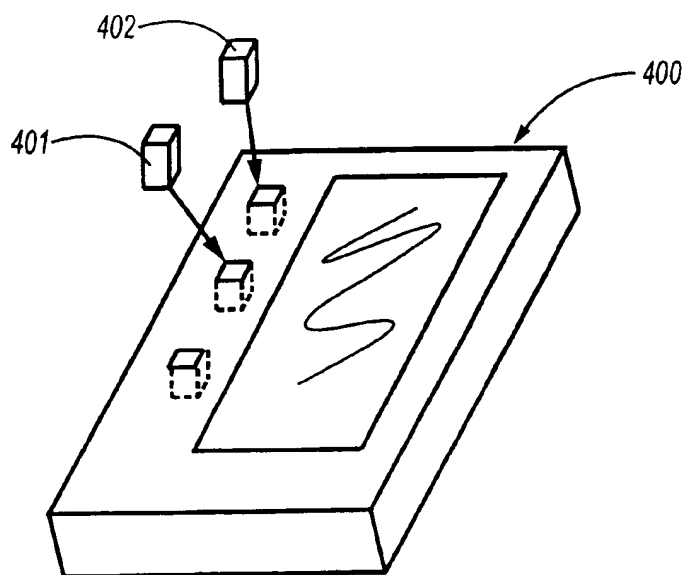
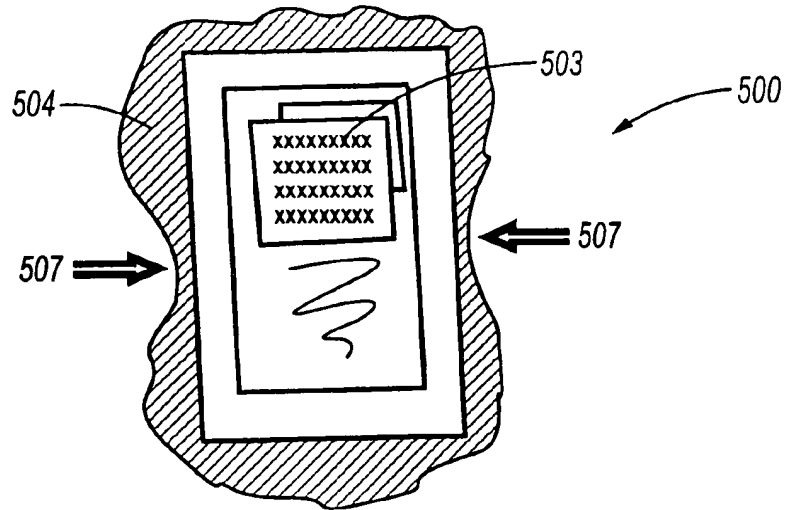
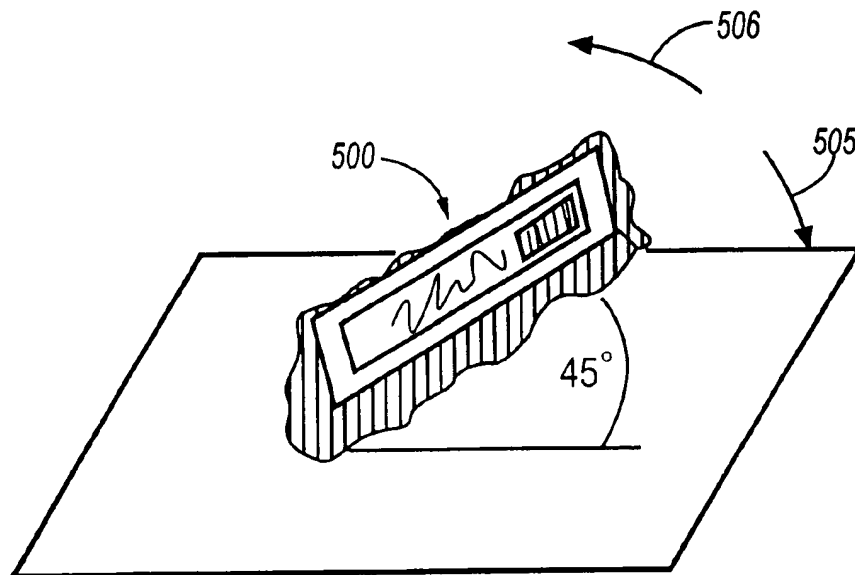


Fig. 28

*Fig. 29**Fig. 30*

*Fig. 31**Fig. 32*

*Fig. 33**Fig. 34*

*Fig. 35**Fig. 36*

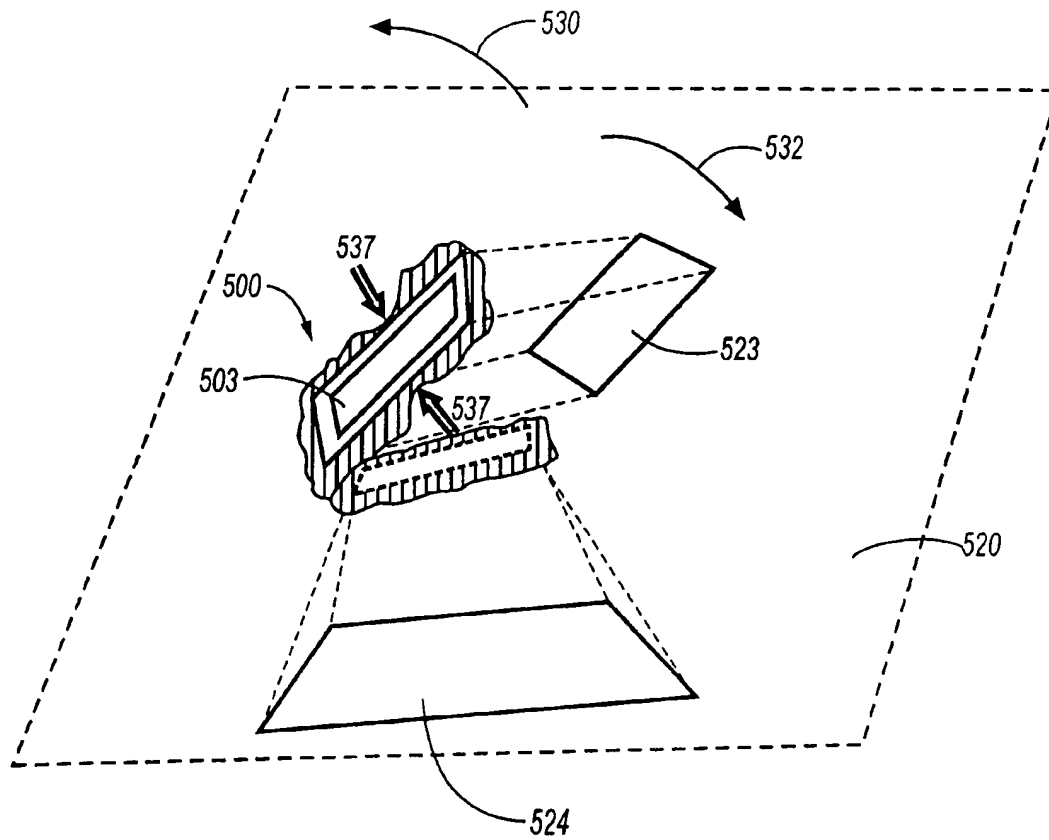
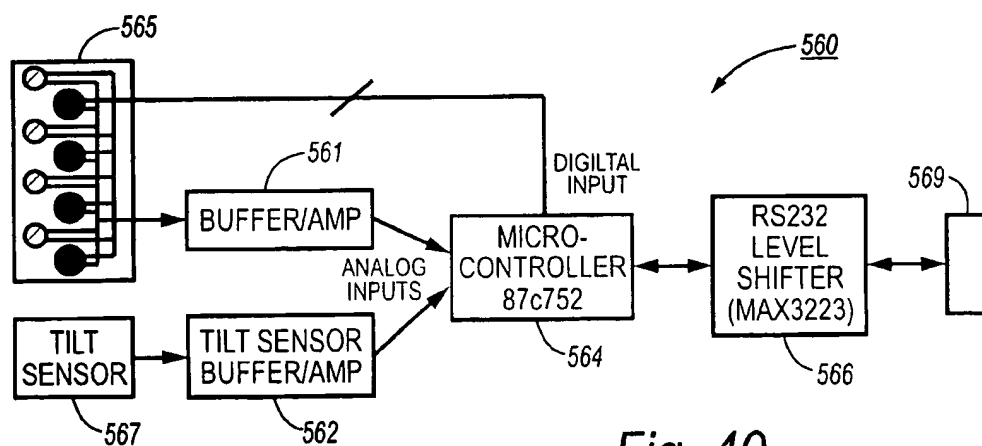
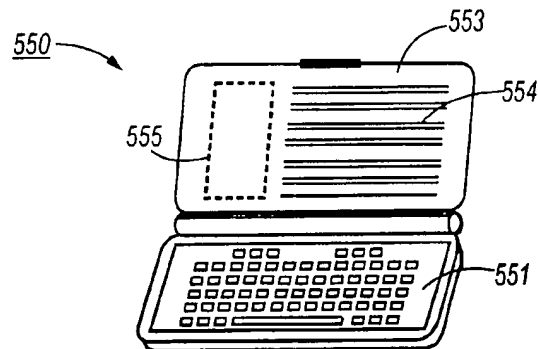
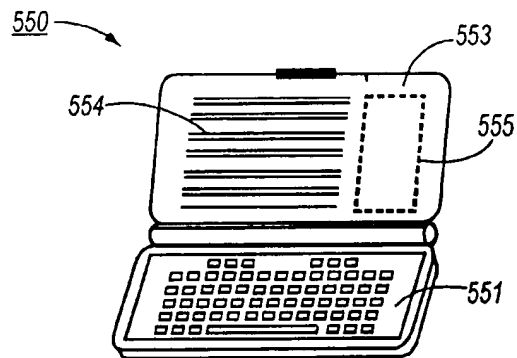


Fig. 37



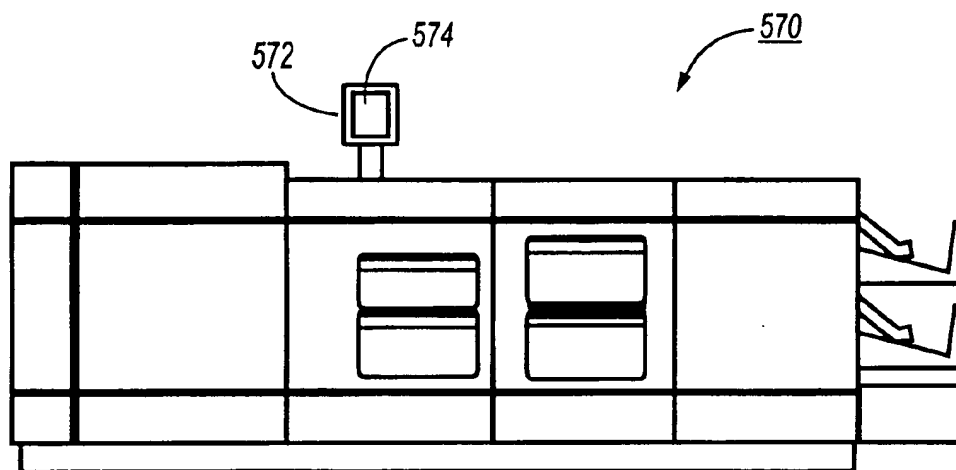


Fig. 41

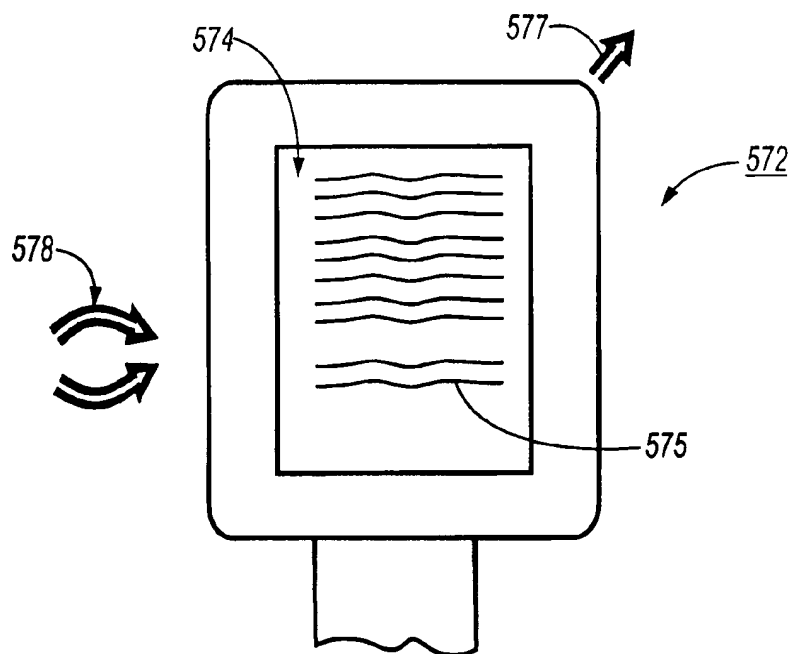
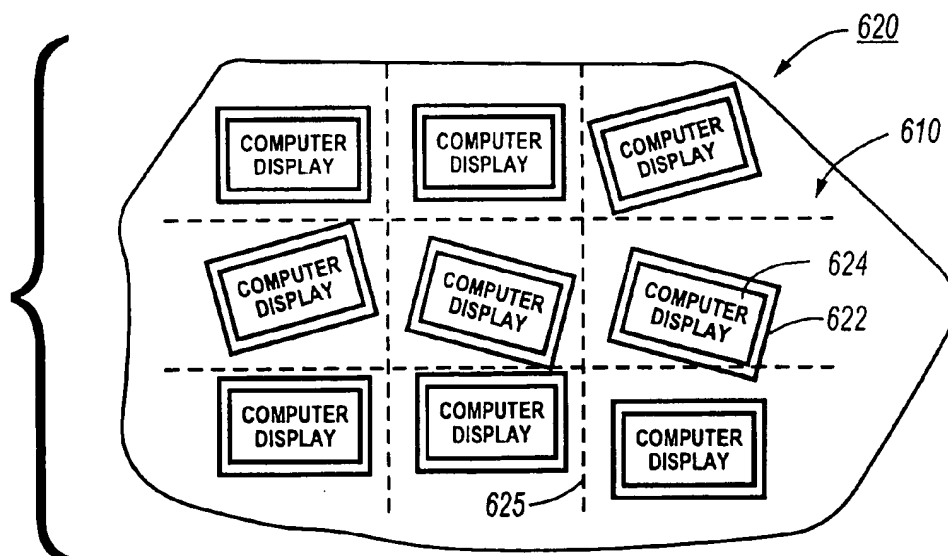
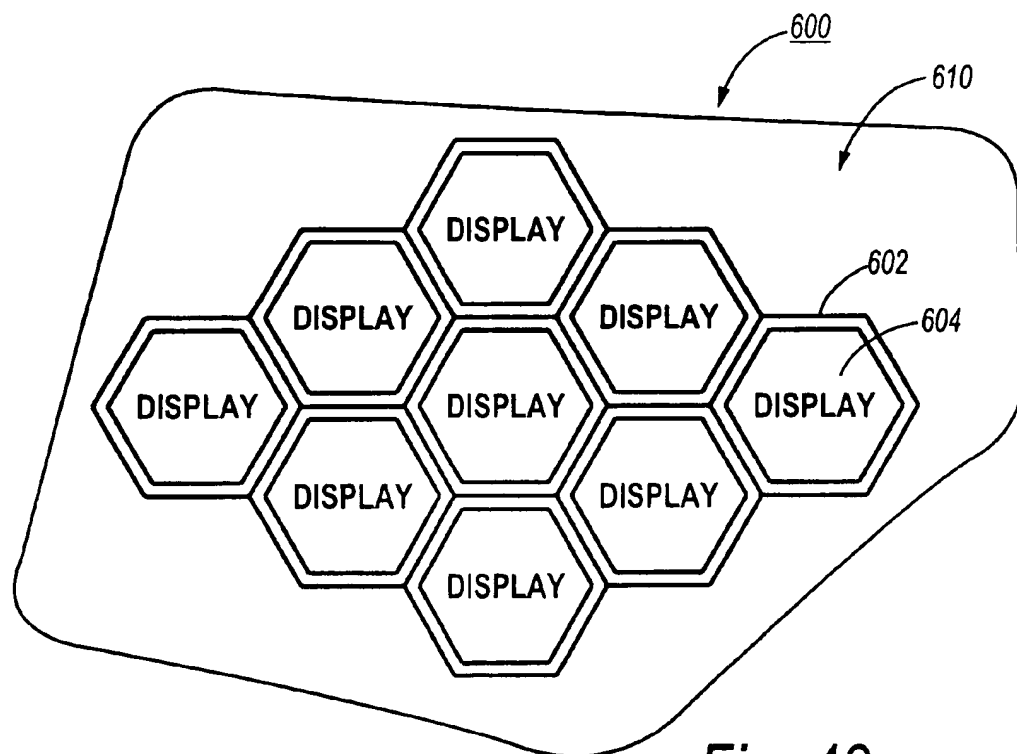


Fig. 42



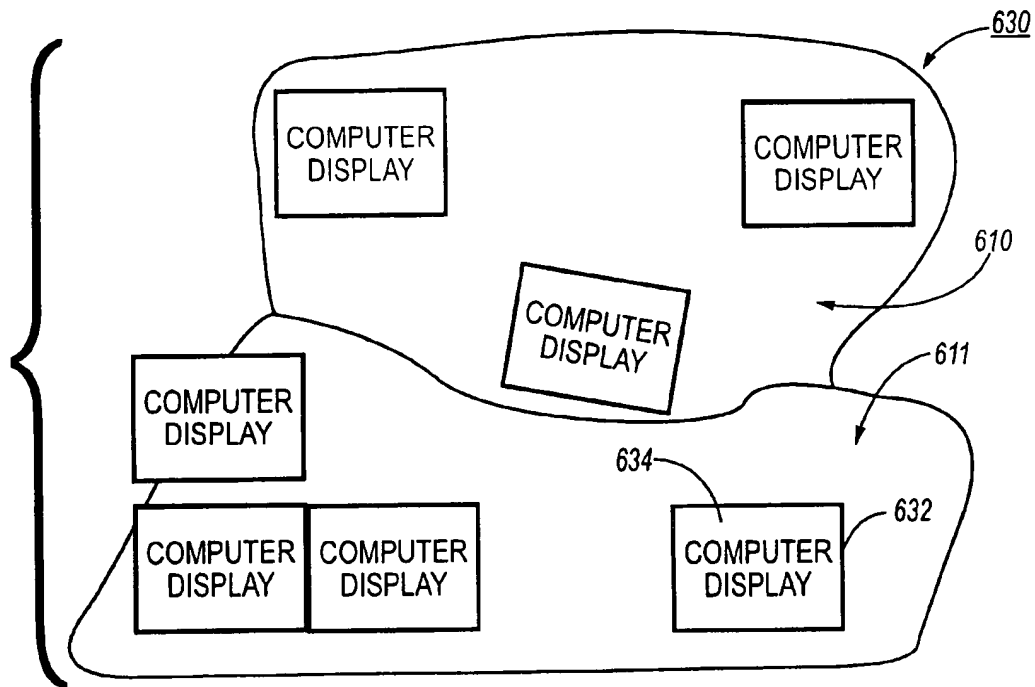


Fig. 45

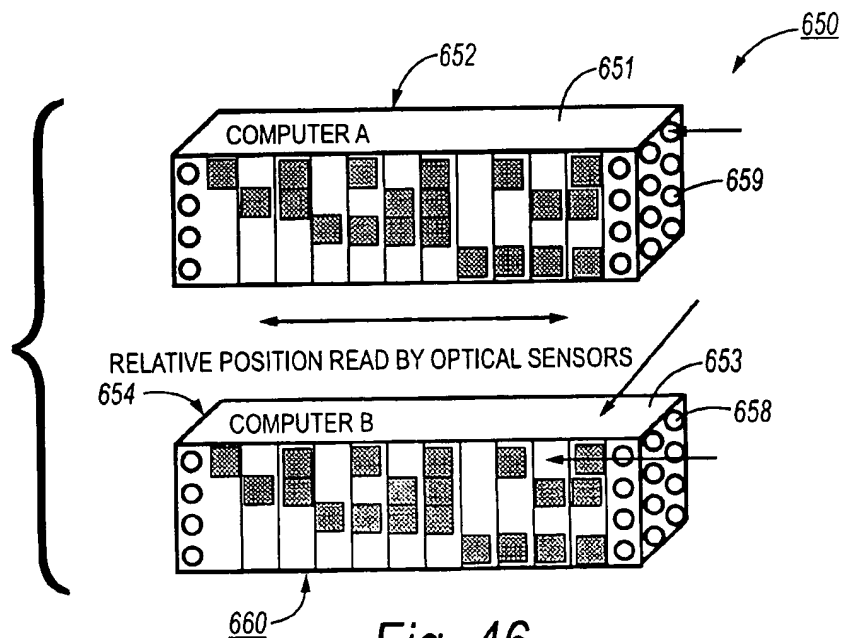
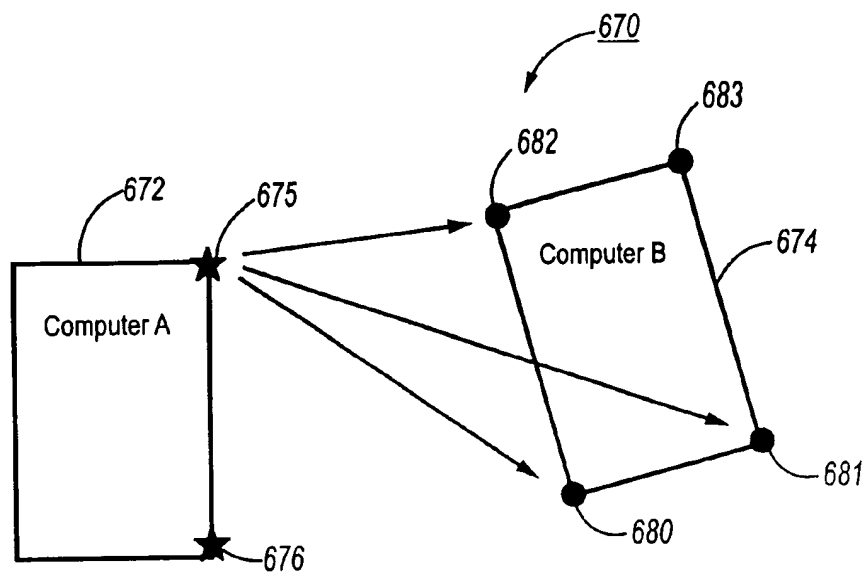
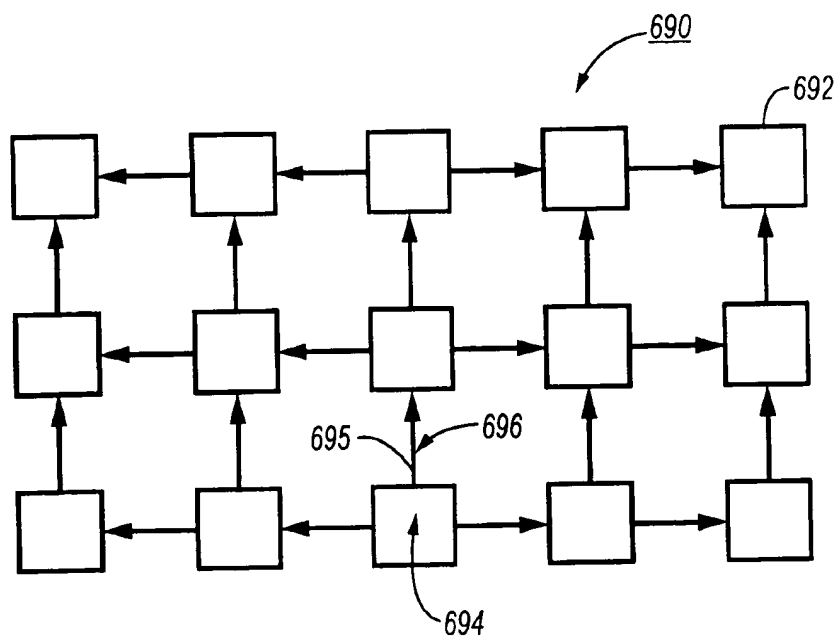


Fig. 46

*Fig. 47**Fig. 48*

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DYNAMICALLY RELOCATABLE TILEABLE DISPLAYS

FIELD OF THE INVENTION

The present invention relates to a dynamically relocatable tileable display apparatus. More particularly, the present invention relates to autonomous tileable computer displays capable of supporting optical, radio, or mechanical interconnections.

BACKGROUND AND SUMMARY OF THE INVENTION

Reliably, quickly, and intuitively transmitting complex commands to small portable computers can be difficult. Small computer devices do not generally have sufficient computer processing power to respond reliably to voice or handwritten (pen based) commands, keyboards are often absent or too small for accurate finger input, and conventional buttons are too large or support too limited a command instruction set. User interface techniques that rely on bulky external modules (full size infrared linked keyboards, tethered data gloves, or camera based gestural recognition equipment, for example) are expensive, often not readily available outside selected sites, and probably too awkward for widespread use in conjunction with consumer level portable computing devices.

User interface designers for portable computers have attempted to compensate for some of these problems by constructing devices that rely on various spatial, positional, or environmental cues that manually or automatically allow for activation of various modes in the device. For example, some laptop computers use the action of opening/closing the lid to initiate automatic bootup/powerdown of the computer without requiring any additional signal input (e.g. such as depressing a "start" button or typing "o_g_o_n" on a keyboard) from a user. Alternatively, the use of small portable computers that automatically switch control modes depending on position, orientation, or room location have been investigated. Buttonless manual control of a portable computer through deliberate user actions such as tilting the portable computer have also been described.

However, all these solutions for interfacing with small portable computers have generally been limited in scope and functionality. What is needed is a user interface system suitable for even very small portable computers (having volumetric dimensions on the order of a one cubic centimeter) that is powerful, can be intuitively operated by an ordinary user with little training, and is still readily capable of modification or extension by the user. The present invention meets these requirements by providing a to manipulatory user interface that responds to a user twisting, folding, bending, squeezing, shaking, tilting, spinning, lifting, or otherwise physically manipulating the computer.

In the manipulatory user interface system of the present invention, the most basic level of manipulation is known as a "senseme". A senseme is defined as a single indivisible type of physical manipulation. A partial list of categories of sensemes include material transformations such as squeezing, twisting, stretching; local spatial transformations such as translation, rotation, orbiting; and environmental transformations based on temperature, light level, or vibration. For example, a small portable computer may support a deformable piece having multiple embedded sensors that detect folding, twisting, or bending of the deformable piece by a user. This computer can also contain a number of accelerometers that sense relative spatial information;

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gyroscopic, radio or infrared positional sensors for determining absolute position; and various thermal or photosensors that respectively detect temperature and light level changes. Intentional or unintentional modifications detected by one or more of these sensor systems can provide the basis for a powerful user interface scheme.

As will be appreciated, each senseme category contains many individually distinguishable members. For example, consider the category of senseme known as a "pinch", a structural transformation generally completed by a user squeezing the deformable piece between a forefinger and thumb. A pinch can be modified by varying its speed (quick or slow pinch), magnitude/intensity (light or hard pinch), portion of deformable piece pinched (top, bottom, or center of deformable piece pinched), or even portion of body used to pinch (right handed pinch or left handed pinch), with each modification being distinguishable as a senseme capable of being mapped onto a computer control command.

Although the wide variety of easily distinguishable sensemes would alone provide a powerful user interface to a computer, the present invention further extends the flexibility of the senseme based user interface by supporting computer control based on a "morpheme" input. The morpheme is a temporally synchronous (or overlapping asynchronous) tuple of one or more sensemes. Note that a morpheme can (and often will) contain more than one senseme. The sensemes combined into a morpheme can come either from the same category (the user pinches with a right hand while tapping with a left hand finger), or different categories (the user pinches the deformable piece with a right hand while modifying the spatial position of the portable computer by tilting it forward).

Any morpheme can in turn be extended by participation in a "sentence". A sentence is defined as a sequence of one or more temporally disjoint morphemes. The sentence level allows definition of a physical manipulatory grammar by appropriate choice of morpheme sequence, and corollary rules governing, for example, use of active (verb like) morphemes, naming (noun) morphemes, or connectors. Other possible grammar constructs used in sentences may include those based on "home" systems. Home systems are general-purpose gestural languages, whose grammar and syntax are not borrowed in any way from a host language. Examples of these languages are gestural languages developed by deaf children of hearing parents who have not been exposed to American Sign Language (ASL), and the "plains talk" of North American Indians, which was used as a trade language.

Accordingly, the present invention provides a method for inputting information to a computer connected to a deformable piece that can be manipulated, and optionally to various position sensors (both relative and absolute), pressure sensors, thermal sensors, or even light sensors. The method comprises the steps of manipulating the deformable piece to provide a first morpheme input to the computer, with the first morpheme input normally triggering a first default action by the computer. The deformable piece may also be manipulated to provide a second morpheme input to the computer, with the second morpheme input converting the normally triggered first default action to a second action. The first and second morphemes (and any subsequent morphemes) together form a sentence that can be interpreted as a command to implement a computer controlled action, whether it be to unlock an electronically controlled door, display a graphical image on a computer display, or begin logging on to a computer network. Advantageously, such a user interface system is well suited for interaction with small com-

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puter devices, and may even be cross-cultural to a limited extent, with ability to squeeze or pinch being universal human attributes.

The present invention is particularly useful for portable computers that can be held in the palm of a hand. If the portable computer is partially or completely surrounded with a deformable material having embedded or contact pressure/deformation sensors, a user is able to gesture with or manipulate the whole computer in order to achieve some desired result. Material deformation can be implemented at various scales. For instance, a computer and connected deformation sensors mounted inside a flexible tube could respond to right angle bending of the tube, or even complex knotting or looping of the tube. In practice however, only minute surface deformations are required, being just sufficient to provide tactile feedback to pressing, pinching, or bending type manipulations. In either case, however, the measurement of location and pressure applied to a surface is sufficient to characterize the mode of interaction (distinguishing a pinch from a prod).

One particularly preferred embodiment of a handheld portable computer that responds to a physical manipulatory grammar in accordance with the present invention includes a computer, a feedback module to provide visual, auditory, or tactile feedback to a user (e.g., processor connected LCD display, audio speaker, or tactile display to present Braille or other conventional touch interface), and co-mounted graspable, deformable piece partially or completely surrounding the feedback module. In addition, various thermal or pressure sensors are mounted to detect handedness of a user, with the grasping hand generally being the non-dominant hand for the user. Depending on the handedness of the user (which can be considered as a morpheme), the displayed data structure is modified. For example, text displayed on an LCD display screen may be automatically shifted rightward on the screen to allow pen based annotation on the left side of the screen, thereby aiding left handed users.

Physically manipulatable user interfaces additionally provide an opportunity for multiple devices to interact in a user friendly manner. For example, a tileable display system having multiple displays with touch sensitive deformable pieces surrounding the display can be used to organize documents based on relative position of contact of each display. For example, if two displays initially showing separate data structures (e.g. two different pages from two different electronic books) are brought together in side by side touching contact, the displayed visual information can alter (e.g. by displaying adjacent pages of a single electronic book). As will be appreciated, one can also use multiple computers connected to physically manipulatable control elements to construct complex commands for organizing data structures.

Additional functions, objects, advantages, and features of the present invention will become apparent from consideration of the following description and drawings of preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an approximately spherical hand holdable portable computer having a deformable surface, a status display, and a pressure sensor array for detecting surface deformations;

FIG. 2 is a graphical diagram illustrating various physical manipulation morphemes, with axes respectively illustrating complexity of senseme tuples required to form a morpheme, and plasticity of a device required to support the physical manipulation;

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FIGS. 3-16 schematically illustrate various preferred classes of physical manipulation morphemes;

FIG. 17 is a graphical diagram illustrating various spatial morphemes, with a first axis illustrating complexity of senseme tuples required to form a morpheme, and a second axis illustrating the degree of positional information needed to support the physical manipulation (moving along a continuum from relative local measurement along a single specified dimension to absolute global measurement with six degrees of freedom determined);

FIGS. 18-26 schematically illustrate various preferred spatial manipulation morphemes;

FIG. 27 is a graphical illustration showing increasing degrees of sensor system complexity that can be used to detect various categories of environmental stimuli, including light effects, thermal effects, the electromagnetic environment, and the vibratory/acoustic environment;

FIG. 28 is a graphical diagram illustrating various physical manipulation morphemes for multiple interacting devices, with axes respectively illustrating the complexity of senseme tuples required to form a morpheme, and increasing level of physical contact;

FIGS. 29-34 schematically illustrate various preferred manipulation morphemes for multiple interacting devices;

FIGS. 35 and 36 are schematic diagrams illustrating "squeeze" and "tilt" morphemes applicable to a portable computer;

FIG. 37 is a schematic diagram illustrating tilt and squeeze morphemes used to control view of large two dimensional data sets with a relatively small display of a portable computer;

FIG. 38 is a schematic illustration representing a portable computer having a display ready to receive annotations from a right handed user;

FIG. 39 is a schematic illustration representing a portable computer having a display ready to receive annotations from a left handed user;

FIG. 40 is an electronic schematic illustrating components of the pressure and tilt sensitive modules of a portable computer such as illustrated in FIGS. 35-39.

FIGS. 41 and 42 are schematic illustrations of a scanner/printer/copier using a paper shaped display interface to support morphemic input;

FIGS. 43-45 are schematic illustrations of tilable displays capable of supporting morphemic input;

FIG. 46 illustrates optical sensors and patterns suitable for use in conjunction with tileable displays such as illustrated in FIGS. 43-45;

FIG. 47 illustrates radio transponders suitable for use in conjunction with tileable displays such as illustrated in FIGS. 43-45; and

FIG. 48 illustrates addressing of multiple tileable displays.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an embodiment of the present invention suitable for supporting a morphemic user interface grammar. Support of the grammar can require detection of a users physical manipulation of a device, detection of relative or absolute spatial location of the device, detection of various environmental factors acting on the device, and even detection and interaction with multiple devices or external computer networks. As illustrated, a device 10 has a deformable surface 20 with an underlying deformation sensor mesh 22

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for detecting surface deformation across or within multiple subregions of the deformable surface 20. The deformation sensor mesh 22 is connected to an internally contained processor 24 having associated memory system 26. For detecting various positional or environmental variables, a sensing system 28 is also provided. The illustrated device further includes a feedback module 33, which may include an externally visible status display 30 or a non-visual feedback module 31 (typically delivering auditory or tactile feedback). In the illustrated device, a communications system 32 for reception or transmission of information to other electronic or computing devices is also provided. All these components can be powered by a power supply 25, which is usually an internally mounted rechargeable battery of conventional construction.

Although the device 10 is illustrated as having an approximately spheroidal and unitary mass, various other shapes are contemplated to be within the scope of the present invention. For example, the overall shape may be similar to various rectangular prisms, or can be ellipsoidal, toroidal, planar, or even be malleable enough to support a wide range of user defined irregular shapes. In addition, multiple cooperating shape elements are contemplated using conventional designs that permit interlocking of multiple shape elements (e.g. using a ball and socket, a lock and key, or slidable or rotatable interlocked components).

Whatever the shape of device 10, for operation of the present invention the device 10 is completely or partially enveloped by the deformable surface 20. The present invention supports use of a great variety of designs and materials for the deformable surface 20, depending on the required plasticity, durability, longevity, and of course, cost constraints. For example, contemplated designs for deformable surface 20 include, but are not limited to:

- a closed or open celled polymeric foam material having a wall thickness of millimeters to centimeters, with thinner walled embodiments being supported (e.g. by adhesive attachment) by an internal hard shell (constructed from polymeric or metallic materials), and those thicker walled embodiments directly supporting (by, e.g. brackets or supports) internal components such as processor 24. Suitable foams may include those composed in whole or in part of widely available synthetic rubbers such as polychloroprene (neoprene), polystyrenes, rubber or nitrile rubber latex foams, polysiloxanes, block polymers including styrene-butadiene or styrene isoprene, or any other conventional material having good elasticity and deformability;
- a thin single layer polymeric surface loosely wrapped around a internal hard shell (the hard shell being constructed from polymeric or metallic materials). For example, a nylon or cotton weave, single layer polyethylene, synthetic rubber (with little or no foam cells present), or natural polymeric materials such as leather wrapped around a polystyrene casing can be used;
- a composite layered surface having a durable polymeric outer layer supported by an inner foam layer; or even
- a polymeric bilayer having an intermediate fluid or gel layer of a viscous or thixotropic material that can be used to support extreme deformations. The intermediate layer can be relatively thick (one the order of centimeters), or in certain embodiments can have a thickness measured on micron to millimeter scales. Such extremely thin layers would allow complex

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twisting, folding, curling, or crumpling actions, and have been described in conjunction with U.S. Pat. No. 5,389,945, assigned to Xerox Corp., the disclosure of which is herein specifically incorporated by reference.

The deformation sensor mesh 22 can be embedded within, or positioned to contact, the deformable surface 20. The deformation sensor mesh 22 can include an array of individual compressional or tensional strain sensors, or alternatively, embedded or attached positional sensors. For certain applications, continuous sensors (e.g. bilayer sheets of capacitance sensors) may be employed. One particularly useful continuous sensor type uses multiple capacitance or resistance strips, with deformation pressure resulting in a positionally localizable analog signal proportional to the applied deformation pressure. Various sensor types can be used, including simple capacitance sensors, resistive strain sensors, analog or digital pressure switches, inductive sensors, or even fluid flow sensors. Depending on the sensor type employed, sensor data can be directly fed to the processor 24 in digital form, or be transformed to digital format by a general purpose analog/digital converter that typically provides a 4 or 8 bit range (although as few as one or as many as 32 bits may be required by various applications). An analog to digital converter may be internal to the processor 24 or provided as an external module. As will be appreciated, the sensor mesh 22 is intended to include combinations of sensors and sensor types, which can be used over the whole or part of the deformable surface 20.

A positional or environmental sensor system 28 can also be supported by device 10. Various sensor modes can be supported, including absolute or relative positional information as determined by gyroscopic sensors, accelerometers, or acoustic or infrared ranging techniques. Environmental sensors, including conventional light, image, thermal, electromagnetic, vibratory, or acoustic sensors can also be present. Depending on the desired application, even costly environmental or positional sensors such as those incorporating differential GPS positioning, image analysis or recognition, acoustic or voice identification, or differential thermal sensors can be used as morphemic input. Such morphemic input, taken in conjunction with morphemic input as detected by sensor mesh 22, can enhance precision and flexibility of a users control of device 10.

As illustrated, both sensor system 28 and sensor mesh 22 are connected to the processor 24 and associated memory 26. The processor 24 and memory 26 are typically mounted within the deformable surface 20, by either direct attachment to the deformable surface 20 or by attachment to a hard casing positioned within the deformable surface 20. Conventional CISC or RISC processors can be used in the illustrated embodiment, with low power processors such as the Signetics 87c752 or 87c751, Motorola 68HC11 or 68582, or ARM 710 being preferred. If convenient, coprocessors such as analog to digital converters or digital signal processors can be used alone or in conjunction with a main processor. Conventional flash, static, or dynamic RAM can be used in the present invention, although for certain applications higher cost embedded DRAM may also be used. In some storage intensive applications, memory 26 can include additional harddisk storage, either located within the device 10 or available through an external connection. As will be appreciated, for many applications use of optional external communications can at least partially supplant use of internal processors and memory (except for that necessary to support required sensor or communication buffering and signalling).

The present invention optionally supports communications with an external computer system 40 using its internal

communications system 32 and associated transceiver 34. The external computer system 40 also includes a transceiver 42, a personal computer or workstation 44, and is connected to a local or wide area network computer system 46. The transceivers 34 and 42 can support various communication protocols and designs, including use of a serial tethered line 36 (using, for example the RS-232C interface protocols), use of infrared signals 38 adhering to widely utilized IRDA communication standards, or use of radiofrequency signal 37 (which can be, for example, a cellular telephone, 900 MHz radio, or digital PCS telephonic communications). Alternative communication standards, or even alternative communication carriers such as those based on optical or acoustic techniques, can of course be employed.

As will be appreciated, in addition to direct communication with external computer system 40, the device 10 can be directly or indirectly maintained in continuous or intermittent communication with a number of suitably equipped electronic devices, including a tablet computer 110, or even a physically manipulatable portable computer 11 similar in design and function to device 10. Communication can be direct to a target device, or through an intermediary retransmitter such as computer system 40. Other possible communication targets include automation control systems, security authorization units, personal digital assistants, notebook computers, or any other suitably equipped electronic system.

Results of communications with external devices, presentation of device stored information, or device status updates can all be provided to a user through processor 24 controlled update of feedback module 33. Feedback to a user can be primarily visual, such as can occur in conjunction with visual display 30. Generally, the display 30 can be a conventional passive or-active matrix liquid crystal display, although use of more sophisticated (and expensive) displays based on various electrooptical or micromechanical techniques can of course be used. In addition, for certain devices a non-imaging display such as may be formed by a small number of status lights (e.g. red or green LEDs), or localized or distributed chromatic changes (in conjunction with a deformable surface 22 constructed with suitable electrochromic materials) may be all that is necessary for visual feedback to the user.

In some embodiments of the invention, visual output through display 30 may be augmented (or even replaced) with a non-visual display 31. The non-visual display 31 can include tactile displays based on internal actuators, auditory feedback, or even displays based on conformational changes in device appearance. For example, one possible feedback display is based on internal auditory speakers (emitting a range of sounds from simple "beeps" to well formed speech, depending on available processor speed and functionality) for providing user feedback. As will be appreciated, non-visual display 31 and its associated actuators or electronics can support alternative feedback modes, including, for example, force feedback to a user through internal actuators, tactile based feedback (e.g. with multiple surface projections for presentation of Braille or other conventional tactile user interface), modifications to the surface texture of the device, or any other conventional mechanism for supplying information to a user.

To better appreciate operation of the present invention, some selected modes of physical manipulation of device 10 are schematically presented in FIG. 1. As seen in FIG. 1, device 10 can be translationally moved in three spatial dimensions, as illustrated with reference to orthogonal force arrows 50, 51, and 52. In addition to translational motion, the device 10 can be rotationally moved in any or all three

spatial dimensions, as represented by arrows 53, 54, and 55. By use of sensor system 28 (alone or in combination with communication system 32), the relative or absolute position and orientation in three dimensions can be determined.

In addition to determining spatial position and orientation through use of sensors 28, the device 10 can optionally use sensor mesh 22 to measure and localize transient or continuing force application, with force vectors and related timing information being determined and interpreted. A few possible force actions (deformation modes) are schematically illustrated in FIG. 1, with arrows 60 and 61 illustrating depression of surface 20 (with the combination representing a squeeze), arrows 62 and 63 illustrating sliding or rubbing deformation (with the combination representing a twist), and the combination of sliding arrows 65 and 66, and outward pull 67, together representing a pinch and outward pull. The strength of the applied force can be measured (e.g. a hard or soft squeeze is differentiated), its spatial expanse found (e.g. to differentiate between poking with a fingertip or a thumb pad), and timing determined (e.g. to differentiate between a quick or a slow depression of the surface). The deformation so caused may be either permanent or transitory.

As will be appreciated by those skilled in the art, each of the foregoing force actions represented by arrows can be considered a senseme. Some temporally distinguishable sensemes (or combinations of sensemes such as the foregoing discussed pinch/pull combination) further represent morphemes used as a basis for a morphemic grammar in accordance with the present invention. All of the following described morphemes can be modified by numerous variations in applied pressure, force utilized, appendages used, body parts, or extraneous intermediary objects used to apply force. In addition, timing of various objects (whether quick, slow, or alternately quick and slow) can modify interpretation of a morpheme. For example, if "squeeze" is taken as a typical morpheme, one can appreciate various squeeze operations such as quick squeeze, slow squeeze, hard squeeze, soft squeeze, narrow squeeze, wide squeeze, squeeze between hands, squeeze between one hand and a user's chest or head, squeeze between one hand and a table or wall, a squeeze made between two pens or two books, or even a squeeze between a user's tongue and the roof of the mouth. For purposes of the present invention, all such squeeze morphemes would be considered members of the "squeeze" class, with individual variations acting as possible modifiers or selected cases, just as a "house cat" might be considered a particular member of the class of "felines", which more generally embraces lions, tigers, and bobcats.

To aid in understanding the diversity of contemplated physical manipulation morphemes, FIG. 2 illustrates selected morphemes arranged by increasing plasticity of the device required to enable morpheme utilization, and by increasing complexity of available senseme tuples required to form or interpret a morpheme applied to a particular class of device. Beginning with the least plastic device and the simplest senseme set used to compose a morpheme, a definition of a possible physical manipulation and typical function invoked by that manipulation of a device similar (but of course possibly more complex) to that described in conjunction with FIG. 1 is presented:

Depress

Definition: Indenting one or more subregions of the device through the application of pressure.

Example: As seen in FIG. 3, consider a device 122 having a display 123. The device 122 supports a graphical illustration software application which allows users to position geometric shapes or user defined graphical objects. The

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device can have four pads 124 placed around it, one on each side. By deforming a particular side, the user indicates a desire to "nudge" the currently selected geometric shape 125 away from that side to a new position 126.

Squeeze

Definition: To deform one or more subregions of a device through the application of vectors of force, some components of which are directed towards each other, which compress the morphological structure of the device. This is a special case of depression.

Example: As illustrated in FIG. 4, consider a device 132 which can display one or more documents in either iconic (closed) or textual display (open) modes. By selecting an open document 135, and then squeezing a deformable edge 134 of the device 132, the user indicates a desire to make the document "smaller", in this case to iconize it as icon 136.

Fold

Definition: To deform a second subregion by bending the first subregion such that it partially or completely overlaps the second subregion. Further deformations can be applied to that new morphological structure on other subregions.

Example: As illustrated in FIG. 5, consider a device 142 which can display documents. Suppose this device 142 has been augmented such that a deformable horizontal "flap" 144 on a top edge of the device 142 can be folded to partially obscure a display 143. When the user makes this folding gesture, the user indicates a desire to password-protect ("hide") the currently displayed document.

Curl

Definition: Deforming one or more subregions of the device by spirally configuring subregions relative to each other in a cylindrical or circular morphological structure.

Example: As illustrated in FIG. 6, consider a device 150 which can display documents in various languages (English, French, etc.). When the user takes such a device 150, curls in a direction indicated by arrow 157 into a tube, and then uncurls it, this "abra-cadabra" gesture tells the device 150 to display the current document in a different language.

Stretch

Definition: Deforming one or more subregions of a device through the application of vectors of forces, some components of which are directed away from each other, the vectors being applied at opposite ends of the device. Example: As illustrated in FIG. 7, consider a device 160 with a graphical software application which allows users to manipulate geometric shapes. By stretching the device 160, the user indicates a desire to "resize" or "rescale" the currently displayed shape 165 to a larger size 166, the amount of resizing being a function of the amount of deformation. Note that SQUEEZING can indicate resizing the currently displayed to a smaller size.

Pinch

Definition: Manipulating one or more subregions by applying vectors of forces, aligned directly towards each other, on opposite sides of the affected subregion(s). This is typically, but not exclusively, accomplished using two-finger tactile force. PINCH is a special case of SQUEEZE.

Example: As illustrated in FIG. 8, consider a device 170 which can copy documents. By performing a "pinching" action 175, the user indicates that they wish the next set of copies to be issued in stapled form.

Dogear

Definition: Deforming a second subregion by folding a first subregion at a logical corner or edge of the second subregion, indicating a marker or location point (e.g. a bookmark) to be later referenced. DOGEAR is a special case of FOLD.

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Example: As illustrated in FIG. 9, consider a device 180 which displays a subset of the pages from a multi-page document. By "dogearing" the upper right corner 185 of device 180, the user indicates that they wish a bookmark associated with the currently displayed page or pages.

Twist

Definition: Deforming one or more subregions of the device through the application of two opposing rotational forces offset from each other by a non-zero difference about some central axis.

Example: As illustrated in FIG. 10, consider a device 190 which, over time, becomes degraded in some aspect of its performance (its disk becomes fragmented, its memory needs garbage-collection, etc.). By performing a "TWIST" gesture 195, the user indicates that they wish the device to "wring itself out", performing, for example, garbage collection.

Relief-Map

Definition: Deforming one or more subregions of the device by raising and or lowering them by either spatial transformation or the addition/removal of material.

Example: As illustrated in FIG. 11, consider a device 200 which can display documents in either one- or two- page format. When the user "scores" the device by making a vertical indentation about the center axis of the device while it displays a single page 206, the device 200 interprets the morpheme to request display of documents in a two-page format as pages 207 and 208.

Rip

Definition: Deforming one or more subregions of the device by introducing a spatial discontinuity, by applying vectors of force to partially or totally disconnect these subregions from the device.

Example: As illustrated in FIG. 12, consider a device 210 which can copy some or all of its information. When the user performs the "ripping" gesture 215, removing one or more subregions, the device 210 copies its currently selected data set onto those subregions 216 and 217.

Perforate

Definition: Deforming one or more subregions of the device by means of introducing a change in the spatial connectivity of the subregions such that a hole is introduced (either temporarily or permanently) in the device.

Example: As illustrated in FIG. 13, consider a device 220 which is used to route messages between various parts of a device network, and which displays this functionality to the user by means of lines 222 representing message pathways. When the user perforates the device 220 with a finger or object 224 to introduce a hole in one of these pathways 222, the system stops routing messages along that pathway.

Similarity

Definition: Deformation of one or more subregions of a device previously configured to represent some other pre-defined object. Typically the device acts in a manner consistent with the behavior of the real-world object when it is manipulated in this manner.

Example: As illustrated in FIG. 14, consider a device 230 which contains text-to-speech and audio input capability, and which presents itself to the user in an anatomically accurate shape of a human head. When the user opens lips 232 on the human head, internal sensors detect opening of the lips and activate text-to-speech capability.

3D Map

Definition: The morphing of a device that can be molded around an external object to permit a sensor mesh to determine simultaneously size and shape of the external object. The range of possible external objects is large but is

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limited by the size of the device's solid inner-housing and the volume of the moldable material in the outer housing. In this system the device has the ability to accurately sense the amount of material from its inner surface to the outer edge of the moldable material (example: via ultrasonic sounding, similar to sonar in water) thus determining an accurate electronic model for the shape of the molded enclosure.

Example: As illustrated in FIG. 15, by pressing a device attached moldable material 244 around the surface of an external object (e.g. a cog 242) a device 240 can automatically generate a CAD model of that object and store it in its memory.

Mimicry

Definition: Deforming one or more subregions of the device such that the resultant morphological structure resembles a known real-world object and through this association of subregions, the device acts in a manner consistent with the object it resembles.

Example: As illustrated in FIG. 16, consider a device 250 containing a computer which contains text-to-speech and audio input capability, and which presents itself to the user as a misshapen blob having the consistency and plasticity of moldable putty or clay. When the user performs the "MIMICRY" action by molding part of the device 250 to resemble an ear, the audio input capability is activated.

In addition to morphemes based on physical manipulation, various morphemes based on varying degrees of relative or absolute spatial positioning are contemplated to be useful in practice of the present invention. To aid in understanding the diversity of contemplated spatial morphemes, FIG. 17 illustrates selected spatial morphemes arranged by increasing knowledge of spatial position required to enable morpheme utilization, and by increasing complexity of available senseme tuples required to form or interpret a morpheme applied to a particular class of device. Beginning with a device having only rudimentary relative positioning functionality for supporting simple spatial sensemes, and ending with a device absolutely positionable to within centimeters anywhere on Earth, a definition of a possible spatial manipulation and typical function invoked by that manipulation of a device similar (but of course possibly more complex) to that described in conjunction with FIG. 1 is presented:

Translate (Relative to Device)

Definition: The linear movement of a device's center of mass from one position in space to another.

Example: Used to substitute for mouse controlled graphical "sliders" in conventional graphical user interfaces. When it is only physically possible to display a small amount of list, large listings can still be searched by "scrolling" a display window in response to the TRANSLATE morpheme.

Shake

Definition: Spatially translating all subregions of a device by repeated movement in opposing directions, such that the net translation is negligible.

Example: As illustrated in FIG. 18, consider a device 260 which is used as a calculating device. When the user performs the "SHAKE" gesture, the device 260 clears its accumulator.

Revolve

Definition: Rotating all subregions of a device by rotating the subregions about a point internal to the device, about any arbitrary plane.

Example: As illustrated in FIG. 19, consider a device 270 which displays an imaged slice of volumetric data, such as medical data from a series of CAT scans. By rotating the

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device about a center point 272 internal to the device 270 to a new position 274, the plane specifying the imaged slice is changed accordingly.

Tilt

Definition: Rotating one or more subregions of a device by rotating the subregions such that one or more components of the rotary force are in the direction of gravity and the amount of rotation is between about -180 degrees and +180 degrees.

Example: Consider a device which displays frames from an animation sequence on the side facing the user. As the device is tilted away, the speed of the animation increases—as its tilted towards the user, the speed of the animation decreases, analogous to operation of a gas pedal.

Flick

Definition: A forwards TILT immediately followed by an opposing backwards TILT.

Example: As illustrated in FIG. 20, consider a device 280 which can transmit some subset of its data to another device. When the user performs the "FLICK" gesture by quickly tilting in the direction of arrow 282, followed by a reverse tilt along arrow 282, the device 280 performs this transmission, towards the device (not shown) pointed to by the ray of the gesture.

Spin

Definition: Rotating one or more subregions of the device by rotating the subregions about a point internal to the device, such that the plane of rotation is one of the device's surface planes. SPIN can be considered a special case of REVOLVE.

Example: As illustrated in FIG. 21, consider a device 290 which can display a frame of video 295 from a video sequence. The user performs the "SPIN" gesture in a counter-clockwise direction, the device displays earlier frames in the sequence; when the gesture is performed in a clockwise direction (arrow 292), the device 290 displays a later frame 296 in the sequence (represented by film strip 294).

Orient

Definition: Rotating one or more subregions of the device by rotating the subregions about the center of the device, such that the plane of rotation is one of the device's surface planes, and the amount of the rotation is a multiple of 90 degrees (i.e. to rotate the device between cardinal compass points). Orient can be considered a special case of SPIN, which in turn is a special case of REVOLVE.

Example: As illustrated in FIG. 22, consider a device 300 which can display a document in either 1 page, 2-page, or 4-page format ("1-up", "2-up", or "4-up"). When the user performs the orient gesture in a clockwise direction (arrow 302), the device 300 increases the number of document pages it is displaying from one page 305 to two pages 306 and 307. Further orient gestures would increase the number of displayed pages. When performed in a counter-clockwise direction, the device 300 decreases the number of pages it is displaying.

Face

Definition: Manipulating one or more subregions of the device such that a first set of subregions is no longer bottom-most and a second distinct set of subregions now assumes the first subregions former position.

Example: As illustrated in FIG. 23, consider a device 310 which displays documents, and which allows users to edit such documents. Consider further the case in which the device presents itself to the user in the form of a cube, in which 6 different documents are displayed on the 6 different faces. When the user performs the "FACE" gesture by

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making a particular face top-most, the document which is now on the top-most face becomes editable by the user, while the document which is no longer top-most is no longer editable.

Lift

Definition: The movement of a device's center of mass in a direction opposite to the current gravitation force acting on the device.

Example: Commanding the device to display the computers file system at a position one level higher in the hierarchy.

Pan

Definition: The application of a TRANSLATION to a device such that it is moved parallel to the front of the user's body, at a substantially constant height.

Example: Viewing a spread-sheet on a device with a display so small only one cell can be shown. By PANing the device, the contents of the current row can be shown in sequence depending on the rate or amount of PAN. However, if the device were rotated away from its current orientation during the PAN, a new row would be chosen. The selection of the row could be dependent on the deviation from the original orientation.

Push-Pull

Definition: Manipulating one or more subregions of the device by spatially translating them such that they are moved along a line of projection from the center of the device to the vertical axis of the user's body.

Example: Consider a device with audio output capability. As the device is "pushed" further away from the body, its audio output level increases. When it's "pulled" towards the body, its level decreases.

Whack

Definition: The application of an accelerative or de-accelerative force to one or more subregions of a device such that said subregions contact or are contacted by an external object, causing an equal and opposite countering force.

Example: As illustrated in FIG. 24, consider a device 320 which can perform long and unpredictable database searches. When the user performs the WHACK gesture (e.g. upon a table 322), the current search is aborted.

Orient (Relative to Environment)

Definition: Manipulating two subregions of the device such that the line drawn between the centers of those two subregions alters its orientation with respect to the surrounding environment.

Example: Displaying a CAD drawing of a machine-part in 3D on the display of a mobile device. As the orientation of the device changes, so too does the viewing angle and position of the rendered image.

Orbit

Definition: Rotating one or more subregions by rotating the subregions and/or the center of mass of the device about some point exterior to the physical boundaries of the device, about any arbitrary axis.

Example: As illustrated in FIG. 25, consider a device 330 which can search a network database, such as the World Wide Web, for information. When the user performs the "orbit" gesture, such a search is initiated. The radius 332 of the rotation 334 specifies the breadth of the search—wider circles specify a wider search. The speed of the gesture specifies the time limit imposed on the search—the quicker the gesture, the more cursory the search.

Orbit Relative to User

Definition: Rotating one or more subregions by rotating the subregions and/or the center of mass of the device about

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some point exterior to the physical boundaries of the device, where said point is proximal to a body feature of the user. This is a special case of ORBIT.

Example: As illustrated in FIG. 26, consider a device 340 which can perform audio output. By performing the ORBIT gesture (in direction indicated by arrow 344) about the user's ear 345, the audio output is activated.

Movement in Room

Definition: The local detection of a device's 3D position relative to reference points found within an enclosing room. Differences in the measured position are used to trigger actions.

Example: A virtual filing system that allows you to save and restore files based on the device's current position in the room. To save a file you might think carefully about the contents of the file and then walk to the position in the room that might be most easily associated with it. When retrieving the file you would use the same thought processes and go back to the position you had associated with the file. On doing so the files associated with that position would be displayed and you would then be able to select the file you were looking for. The system is useful because the human mind is very good at remembering information that is spatially organized rather than in some abstract information data structure.

Movement Between Widely Separated Sites

Definition: Manipulating one or subregions of the device such that the detected absolute spatial position of those subregions is changed.

Example: Consider a device which can display information from a database of client information. When the device is moved to a different client site, the device automatically updates its display to display information for the nearest client site.

In addition to morphemes based on physical manipulation or spatial positioning, various morphemes based on sensed environmental conditions are contemplated to be useful in practice of the present invention. To aid in understanding the diversity of contemplated environmental morphemes, FIG. 27 illustrates selected environmental morphemes loosely arranged in order of increasing sensor complexity needed in some commonly sensed environmental categories. For each of the proffered categories, some selected sensing systems supportable by a device such as that described in conjunction with FIG. 1 are presented:

Light

Definition: Manipulating one or more subregions of the device such that the amount of light falling upon those subregions changes.

Example: Consider a device used in a lecture hall to take notes. When the room lights are turned on, the light sensors detect this and turn down the backlight to conserve energy. When the room lights are turned off (e.g. during a slide show) the light sensors detect this and turn up the backlight to increase viewability.

Light sensors can range from thresholded binary light detectors, to light pattern detectors, to full imaging systems. Advanced techniques can include image analysis and recognition to identify objects or persons.

Heat

Definition: Manipulating one or more subregions of the device such that the amount of heat applied to those subregions changes.

Example: Consider a portable computer which has a stylus for entering text. By looking at the heat profile along the back surface of the computer, the computer can detect whether it is being held with the left hand, the right hand, both hands, or neither hand, and update its interface accordingly.

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Thermal (heat) sensors can range from simple temperature sensors to sophisticated differential thermal mappers and thermal imagers.
Electromagnetic

Definition: Manipulating one or more subregions of the device such that the electromagnetic spectrum applied to those subregions changes.

Example: By analyzing the radio spectrum, the device can derive estimates as to its absolute spatial position, and use that to alter its functionality.

Electromagnetic detection can include magnetic compasses, radio detection, or GPS signal detection. More advanced techniques can include electromagnetic spectrum analysis and interpretation, such as roughly determining location based on available radio signals.

Vibrate

Definition: Manipulating one or more subregions of the device by vibration.

Example: Consider a device which displays textual information. When the user takes the device on the bus, the ambient vibration level sensed by the device changes, and the device increases the size of the displayed text to help the user compensate.

This class of environmental morphemes can include detection of intermittent contacts, low frequency rumblings, or acoustic level detection. More advanced techniques requiring greater processor power include maximum frequency identification, spectral analysis of acoustic frequencies (enabling the device to distinguish background environmental noises from speech, for example), or even speech based identification of persons in the vicinity of a device.

In addition to morphemes based on physical manipulation, spatial position, or sensed environmental factors, various morphemes based on cooperation between multiple interacting devices are contemplated to be useful in practice of the present invention. To aid in understanding the diversity of contemplated spatial morphemes, FIG. 28 illustrates multidevice morphemes arranged by an increasing level of possible physical contact, and by increasing complexity of available senseme tuples required to form or interpret a morpheme applied to a particular class of device. Beginning with a device having only rudimentary edge deformation functionality for supporting simple spatial sensemes, and ending with complex deformable or embeddable devices that can be wrapped about each other, a definition of a possible multidevice manipulation and typical function invoked by that multidevice manipulation of devices similar (but of course possibly more complex) to that described in conjunction with FIG. 1 is presented:

Touch

Definition: To move one or more subregions of a device such that they enter physical contact with a subregion of a second device, in any alignment and to any extent. Or, to take two devices so aligned and remove that alignment.

Example: Consider two portable computers 350 and 351, the first of which contains a database, and the second of which contains an IRDA port. When the user touches the first computer 350 to the second computer 351, the database is transmitted via the second computer's port.

Match

Definition: To move one or more subregions of a device such that they enter physical contact with one or more subregions of a second device, with the subregion(s) of the first device and the subregion(s) of the second device being aligned along one or more edges. Or, to take two devices so aligned and remove that alignment.

Example: As illustrated in FIG. 30, consider, multiple devices 360, 361, and 362, which contain different versions

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of the same basic database. When the user MATCHes the first device 360 to the second device 361, followed by matching the third device 362 to the matched first and second devices, their databases are reconciled (synchronized).
Stack

Definition: To move one or more subregions of a device such that they enter physical contact with a subregion of a second device, such that the first device is now located above, but physically adjacent to, the second device. Or, to take two devices so aligned and remove (i.e. unstack) that alignment.

Example: As illustrated in FIG. 31, consider a set of devices 370, 371, and 372, each of which is displaying a frame of video from a longer video sequence. When the devices are stacked, the ordering of the stacking specifies an order for the video editing, and a single composite video is now produced.

Tile

Definition: To move one or more subregions of a device such that they physically contact with a subregion of a second device, such that the first device and second device now form a single seamless spatial unit or to take two devices so aligned and remove that alignment. TILE is a special case of MATCH.

Example: As illustrated in FIG. 32, consider a set of devices 380, 381, 382, 383, each of which can independently display a portion of a large photograph. When the devices are tiled, each device displays the portion of the photograph appropriate to its current relative position in the tiled grid.
Relatively Align

Definition: To move one or more subregions of a device such that they engage in a particular spatial relation to one or more other devices, where said devices are not touching.

Example: As illustrated in FIG. 33, consider a set of devices 390, 391, 392, and 393 which are displaying a multi-page document. Whichever device is presently placed at the far left (device 390) displays the table of contents, whichever one is presently placed at the far right (device 393) displays the index, and the others display pages according to their respective locations. As different devices can have different display capabilities, moving them about can alter the document display. For example, if only one of the devices has a color display, when it is moved from second position to third position then (a) the device which was in third position, displaying page #2, now displays page #1, and (b) the color display, which was displaying page #1, now displays page #2 in color.

Wrapping/Embedding

Definition: Manipulating one or more subregions of a device such that these subregions spatially occlude or are spatially occluded by some portion of the second device.

Example: As illustrated in FIG. 34, consider a first device 400 which contains the infrastructure to support the filtering of email. Consider a second set of devices 401 to and 402 which implement particular email filters. When the user physically embeds device 401 (or 402) into the first device 400, by which the first device 400 now wraps the second device 401 (or 402), the particular email filter supported by the second device is activated.

As those skilled in the art will appreciate, combinations of any of the foregoing described morphemes based on physical manipulation, spatial position, environmental conditions, or multiple interacting devices can be extended by participation in a morphemic "sentence". A sentence is defined as a sequence of one or more temporally disjoint morphemes. Typically, between about 1/10th of a second and 2-3 seconds

suffices to distinguish morphemes within a sentence. Of course, in some circumstances and indefinite time period may elapse. The sentence level allows definition of a physical manipulatory grammar by appropriate choice of a morpheme sequence, and corollary rules governing, for example, use of active (verb like) morphemes, naming (noun) morphemes, or connectors. Just as the position and relation of words in a sentence define the sentence's meaning (e.g. "horse chestnut" is not the same as "chestnut horse"), similarly the position and relation of morphemes in a manipulatory sentence define the sentence's meaning. For example, in a communication mode a FLICK followed by a WHACK could mean "transfer data and erase the local copy", while a WHACK followed by a FLICK means "power on the device and transfer data". In other settings, a FLICK or a WHACK could mean something entirely different. To better understand construction of morphemic sentences, the following examples are discussed:

Data Transfer Sentence

Consider a device which can transmit some or all of its information to another device. Furthermore, this transmission can be done either unencrypted, or encrypted (to increase security). Furthermore, this transmission of a text+graphics document can either include the graphics, or omit them (to save time). Suppose that the user wishes to perform the command "Transmit the information in document A, encrypted, omitting graphics, to machine B". Then a gestural sequence (morphemic sentence) to support this could be:

DEPRESS—the user presses on a displayed representation of A, indicating that A is to be selected for an upcoming operation

FLICK—the user flicks the device in the direction of device B, indicating that the operation is a transmission to B

FOLD—the user folds the top quarter of the device over the lower three-quarters, indicating that the transmission is to be encrypted.

TWIST—the user twists the device about its central axis, indicating that the data is to be "wrung out", i.e. the graphics are to be omitted

SQUEEZE—the user squeezes the device, indicating that they are confirming that the operation is to proceed.

Note that none of these gestures, in isolation, performs an act—the "ensemble" of temporally separated morphemes must be interpreted in order to form the complete action.

Drawing Modification Sentence

Consider a device which displays geometric shapes for user manipulation. Furthermore, one of the manipulations supported is to resize (or rescale) a shape. Furthermore, suppose that this resizing can be done either aliased (jaggy) or anti-aliased (edges are smoothed). Suppose that the user wishes to perform the command "Resize shape A by 120%, about the X axis only, using anti-aliasing". Then a morphemic sentence to support this could be:

DEPRESS—the user presses on a displayed representation of A, indicating that A is to be selected for an upcoming operation

STRETCH—the user stretches some portion of the device, indicating that the operation is to be a resize. When the user starts stretching, a portion of the status display displays "100". The user continues to stretch until the status display reads "120"

RELIEF-MAP—the user "scores" the display by making a horizontal line of depression, indicating that the operation is to take place only about the horizontal (X) axis.

DEPRESS—a circular thumb stroke is made in a different area of the device, indicating that anti-aliasing (smoothing the edges) is to be performed.

Database Presentation Sentence

Consider a device which contains various personal information databases, such as a list of phone numbers, a list of addresses, and a calendar. Suppose that the user wishes the most appropriate of those databases displayed. Then a gestural sequence to support this could be:

SPATIAL LOCATION—the user carries the device such that it is spatially proximate to either the telephone, the address book, or the refrigerator (where the family calendar is displayed), whichever is appropriate.

DEPRESS—the user touches the device to activate the operation. The device now displays the personal information appropriate to that location.

Database Retrieval Sentence

To extend the foregoing example of a database presentation sentence, consider two computers which contain calendar databases. If the user wishes to synchronize the calendars, a suitable gestural sequence to support this could be:

SQUEEZE—the user squeezes the device to activates its gestural recognition capabilities.

ORBIT—the user orbits the device about the surface of the other device 3 times, indicating a desire to only match data for the next 3 weeks.

MATCH—the user matches the edge of the device to the edge of the calendar, indicating a desire to "match" contents between the two devices.

Printer/Copier Control Sentence

Consider a device which can produce paper copies of documents. Suppose that the user wishes to tell such a device to produce a stapled, two sided copy of document A, enlarged to the next greater size. Then a gestural sequence to support this could be:

DEPRESS—the user presses on a displayed representation of A, indicating that A is to be selected for an upcoming operation

RIP—the user introduces a spatial discontinuity into a portion of the device, indicating that the upcoming operation is to be a copy ("carrying away" some of the data).

PINCH—the user pinches the upper left corner of the device, indicating that the copies are to be stapled.

SQUEEZE—the user presses on the front and back of the device, indicating that the copy is to be two-sided.

STRETCH—the user stretches the device, indicating that the copy is to be an enlargement to the next greater size.

FACE—the device typically has its paper emitter on the bottom, preventing users from making copies accidentally. By facing the device such that the emitter is on the side, the copying operation is initiated.

Light Based Control Sentence

Consider a device which can display documents. Suppose the user is using the document while seated on a train, and wishes the document to display itself with a backlight when the train enters a tunnel, and wishes the document to display itself in a larger font when the train rumbles over rough tracks. Then a gestural sequence to support this could be:

SQUEEZE—the user squeezes on the device, indicating that a loss of light is to be compensated for by a backlight.

LIGHT—as the train enters a tunnel, the LIGHT gesture

is made, and the device turns on the backlight.

WHACK—the user briskly raps the device against the palm of their hand, indicating that their desired preference for adjusting hard-to-read documents is to increase the font size.

VIBRATE—as the train goes over a bridge, the vibratory gesture is sensed. Because of the position of this VIBRATE morpheme (after the preceding WHACK to gesture) in this

morphemic sentence, the device now increases the font size on the displayed text.

LIGHT—the user puts the device into his suitcase, making the LIGHT gesture. In this context (with no SQUEEZE before it), the LIGHT gesture causes the device to power-off its display.

To better appreciate utility and construction of devices in accordance with the present invention, several examples of devices are now described:

Portable Computer with Squeeze and Tilt Control

A handheld portable computer 500 (e.g. a 3Com® PalmPilot®) capable of being fitted with deformable, pressure sensitive edging 504 is schematically illustrated in FIGS. 35 and 36. The computer 500 supports a name and address software application, providing a user viewable name-address entry field on display 503. In this embodiment, a user can squeeze the deformable, pressure sensitive edging 504 (squeeze arrows 507) of the computer 500. In response, the name and address software application causes the display 503 to animate by slowly incrementing (scrolling) through the name list from "A" towards "Z" entries. When the user squeezes edging 504 again, the software application stops the scrolling animation. Scrolling functionality is further enhanced by the use of a tilt sensor, which allows the computer's behavior to mimic conventional rotatable address books. If the computer 500 is tilted away from the 45 degree angle at which someone might typically hold it, the scrolling rate is increased. In this application, the closer the computer 500 was tilted towards the user (as indicated by arrow 506 of FIG. 36), the faster the scroll rate toward "Z". However, if a user tilted the computer 500 back past the neutral 45 degree position (as indicated by arrow 506 in FIG. 36), the animation would move backwards with a velocity related to the magnitude of tilt. In this way it was possible for a user to search for items in a long list in a very natural way, while only using one hand.

In an alternative mode schematically illustrated in FIG. 37, scrolling speed can be completely controlled by pressure. The greater the squeeze pressure (arrows 537), the faster the list scrolls. Release of the applied pressure causes the scrolling to halt. In this alternative user interface strategy, application tilt (as indicated by orthogonal tilt arrows 530 and 532) could be used to change the direction of the scrolling through the list, allowing a user to search portions of a large two dimensional data set (schematically illustrated as a data plane 520) that is not entirely visible either horizontally or vertically on display 503. By simply tilting the display 503 of computer 500 as if it were a window through which the data plane 520 can be viewed, any particular portion of the data plane (for example, data subset 524) can be viewed. As will be appreciated, in both the foregoing modes the speed of scrolling, the specific neutral tilt angle, and required pressures to initiate scrolling changes can be adjusted to fit a particular user.

Portable Computer with Handedness Detection

Pressure sensors have been added to augment a conventional keyboard 551 enabled user interface to a hand holdable Windows® CE class computer 550 (i.e. a Cassio® Cassiopia®) schematically illustrated in FIGS. 38 and 39. In this embodiment, user handedness was determined by using pressure sensors positioned on a right back-edge and a left back-edge of computer 550. User studies have found that the difference in pressure between the right and left side gave a direct indication of handedness of a user. As respectively illustrated in FIGS. 38 and 39, handedness was used to justify formatted text 554 to the left (FIG. 38) or right (FIG. 39), thereby allowing more space 555 on display 553 for an electronic annotation pen to be used to mark-up the text.

For both the embodiment of the invention illustrated by FIGS. 35–37, and the foregoing embodiment illustrated in FIGS. 38 and 39, material deformation of a spongy, elastic, or otherwise deformable material must be measured. Although various techniques can be used to measure material deformation, including those based on imaging or fluid volumetric changes, one particularly useful technique is based on the use of pressure transducers. Commercially available sensors measure pressure (indicative of material deformation) by converting a pressure change to a change in electrical characteristics. For example, inexpensive sensors that change resistance in response to pressure can be obtained in a variety of shapes and sizes, including paper thin sensors, and easily bendable sensor strips. Sensors of this kind can be customized to any particular shape or form that a gestural UI might require. The change in resistance is usually linearly related to pressure, with the sensor generally being placed in a potential divider network to model the pressure as a change in potential. For a practical circuit the resulting signal needs to be amplified, buffered and translated such that the change in value from minimum pressure to maximum pressure spans a useful range. The modified signal can now be fed into an analog to digital converter (ADC) to produce a digital representation of pressure. An 8-bit ADC can typically be used for most applications, however, if greater sensitivity to pressure changes is required, a higher resolution ADC (e.g. 16-bit ADC) can be used. As will be appreciated, the ADC could be memory mapped into the processor's address space as a peripheral, or alternatively supplied as a retrofitted pressure interface to existing computers capable of benefiting from this system. Since an RS232 connection is an interface that is almost universally available on portable computers, one strategy is to have the parallel output of the ADC converted into a serial RS232 frame using a serializer such as a UART and then level-shift and buffer the signal as specified by the RS232 standard. At the computer end of the serial interface, another level-shifter and UART, the output of which is readable by the processor, performs the serial-to-parallel conversion.

As described with reference to FIG. 40, in realizing a working system a microcontroller 564 (a Signetics 87c752) with an ADC built in to combine many of the I/O tasks in a single chip can be used in combination with level shifter 566 (a MAX3223). This approach has the advantage that intelligent processing of the input signal is possible with software. Tilt measurement was provided by a tilt sensor 567 connected to a buffer/amp 562 to supply an analog signal to microcontroller 564. The pressure measurement can also be encoded within a protocol across the serial link. This particular microcontroller 564 has five ADC inputs, but by making use of eight digital control lines, it is possible to use only one ADC input and one buffer amplifier 561, to measure up to eight pressure points with pressure sensors 565. This is achieved by using the control lines to select only one sensor at a time and take a reading for each using a single input to the ADC. After eight sensors have been selected, eight readings are acquired in memory. The design is practical because the microcontroller can take measurements and make analog to digital conversions at a rate far higher than is needed to communicate with a host computer 569.

For scrolling or handedness based software applications, 16 levels were determined to be adequate for representing a pressure measurement. In order to have a high data throughput to the host computer 569, each measurement was encoded in one byte of an RS232 frame such that the four lowest bits were the pressure representation and the highest

four bits were the sensor ID. Each frame of the RS232 data was therefore completely self contained. Of course any protocol that limits itself to a specific number of devices in its address space will eventually have the problem that someday applications might be designed that need to reference far more devices than are supported. The solution used in this protocol is to reserve the sensor ID number 15 as a special value that can extend the semantics of the encoding to include an arbitrary number of bytes representing a sensor or value. For the described software applications, the commonly used RS232 frame format (1 start, 8 data no parity, 1 stop bit at a baud rate of 9600) was chosen.

In operation, the host computer 569 determined handedness by utilizing information about the current pressure exerted on two subregions—one, on the back of the device, occupying roughly the left half, and the other, also on the back of the device, occupying the right half. The current pressure values were converted from analog to digital form, such that a digital value of 0 (zero) represents no pressure, and a digital value of, for example, 15 represents maximum pressure. The detection circuitry then proceeds:

if (left_sensor is high AND right_sensor is high) then conclude that the user is gripping the device with both hands

else if (left_sensor is high AND right_sensor is low) then conclude that the user is gripping the device with the left hand only

else if (left_sensor is low AND right_sensor is high) then conclude the user is gripping the device with the right hand only

else if (left_sensor is low AND right_sensor is low) then conclude that the user is gripping the device with neither hand

Also, to optimize communication, pressure values are only sent when they change. In order to account for jitter and error in the pressure sensors, a sensor is only considered 'high' if its value is higher than some minimum threshold (e.g. '2' on the 0 to 15 range).

Scanner/Printer/copier Supporting Edge Deformable Display

A scanner/printer/copier device 570 is schematically illustrated in FIG. 41. As seen in FIG. 41 (and in more detail in FIG. 42) the device 570 supports a display 574 having a deformable edge 572, with the combination roughly shaped like a piece of paper. In operation, a user can place a written document in the device 570 for scanning. An electronic version of the scanned document is displayed (i.e. as text 575 in FIG. 42) on the display 574. By outwardly pulling the deformable edge 572 as indicated by arrow 577, a user can instruct the device 570 to resize the document before printing or copying. Pinching opposing sides of the deformable edge 572 (arrows 578) can further instruct the device 570 to print double sided copies. As will be appreciated, various other morphemes can be used to provide a simple interface for interacting with device 570.

Tileable and Stackable Portable Displays

Multiple autonomous display tiles having an onboard display controller and at least one surface consisting substantially of a conventional display are particularly useful for the practice of various aspects of the present invention. Such tiles can be interconnected in response to various morphemes such as TOUCH, FLICK, RELATIVELY ALIGN, or WHACK, or even can be operated without substantial user mediated morphemic input in certain situations.

Advantageously, tile positioning can be used as an interface specifier in and of itself. For example, each display tile

can contain a video segment in independent memory. Shuffling or reorganizing the tiles can allow users to physically manipulate the sequence of video segments to affect a physically manipulatable video editing system. Using the card analogy, tiles can be used to re-sequence documents, pages within a document, audio annotations, voice mail, or other temporal media contained within the tiles. The resultant sequence can then be played as a whole by using the tiled structure as a unit.

For purposes of the present invention, display tile array configurations can be categorized as follows:

Close-packed display tile array 600 (FIG. 43) in which tiles 602 are arranged to span a surface 610 in closely abutting, but not overlapping relationship, such that the continuous display area is maximized (i.e. seamlessly). As will be appreciated, the tiles could themselves form a freestanding continuous surface, or they could be disposed on a table or other suitable support. Each of the tiles 602 supports a display 604 sized to substantially cover a front surface of each tile 602. In certain embodiments, a back surface of each tile 602 can also support a display. Advantageously, this would allow for creation of free standing displays with images visible on the front and back. The surface 610 can be a plane, a sphere, or any arbitrary shape that permits tiling.

Loose-packed display tile array 620 (each tile 622 having a display 624 as seen in FIG. 44) in which tiles 622 are slotted into a lattice pattern (indicated by dotted lines 625). Each tile can be considered to be situated in a regular bounded lattice slot (namely, the lattice slot that contains a defined center of each of the tiles) within the lattice where the dimensions of the bounded slot are no more than a few times the maximum dimension of the tile, and there is no more than one tile in any slot. Within the lattice regions any of the tiles can be positioned arbitrarily and still retain the same inter-relationship with the group. It is still possible for tiles to touch one another at the boundaries of two or more lattice slots, however, this is not a requirement.

Free-format display tiles 630 (each tile 632 having a display 634 as seen in FIG. 45) are similar to loose-packed display tiles 620 where the size and shape of the lattice slots may vary freely (e.g. the dimension of a lattice slot may be many times the maximum dimension of any of the participating tiles). The only constraint on the arrangement is that there must be no ambiguous relationships about the relative connectivity of each of the tiles 632. That is to say, a tile that is to display the next piece of information to one side of another tile must be unique and not be confused with the task of another tile in the tiling lattice.

3D display tiles (packable display tiles) are created by extending the three foregoing display tile categories. However for close packed tiling of display tiles, packed devices in the center of a 3D structure would not be available as the user interface. This may not matter as the surface of the 3D shape will expose a area that will have unique affordances for some classes of application. For instance, cubic tiles packed into the shape of a large cube can display, using the six faces of the larger cube, the various projections that could be rendered by viewing a 3D CAD drawing from each degree of freedom.

As will be appreciated, display tiles need not be rectilinear but can be hexagonal, circular, or of arbitrary shape and size. The size of tiles need not be constant for all tiles within a larger structure. Tiles need not be aligned but may require proximity to indicate adjoining points or edges.

Tiles need not be in physical contact to define they are joined in a group activity but instead this may be a pro-

grammed function. The connectivity can also be discovered through a radio network from a coordinating server or from a distributed algorithm that draws in as many computers as necessary for a task, using the wireless network to negotiate the resources it needs. The tiled computers may also be connected by wired networking systems, although in cases where the topology might need to rapidly change, this is not as desirable as a wireless system. An example of a wired networking system of this type is a system that uses the intermit to include many computers in a single task, one in which each computer knows its relative position even though they may be separated by rooms or in the extreme cases buildings, cities or countries. However, in general the most useful case of display tiling is when the tiles are proximate enough that they can all be viewed by one person to create a display medium whereby the viewing experience is an enhancement over using a single display. Accordingly, tiles can operate as either a single larger contiguous structure or they can retain individual properties and independent functions or a combination of both. (e.g., jumbo-tron like function, 12x12 small displays as used in a TV studio, or picture in-picture features found in commercial TVs or editing suites).

Depending on the type of packing, various schemes can be used to allow for permanent, intermittent, or even one-time communication between display tiles. For example, close packed tiling can make use of wired connectivity between computers or could use a variety of wireless or optical communication technologies. In the case of wired connectivity, edge mounted conventional plug and socket connectors may be used to create a rigid tiled array. Plug and socket systems lend themselves to parallel connections for bulk and high-speed data transfer. They also provide a convenient method of power distribution, which can allow for one of the tiles providing a power source that supports the rest of the array. A plug and socket connection between tiled computers 692 in a tiled computer array 690 (with both data and power transfer shown) is schematically illustrated by lines 695 in FIG. 48.

The exact design and locations of electrical connectors depends on the intended use, and subsequently, the shape of tile components. For applications where large seams between displays are acceptable, simple rigid connectors could be attached to the center of each edge, providing connectivity to all the surrounding tiles. Other applications might require a more complex design. For example, applications which require high-quality information display on a seamless array surface (i.e. tiled blueprints), might employ spring-loaded contacts on the four edge connectors. The spring mechanism allows all array connections to be made below the display surface, while tiles can still be inserted and removed from the interior of the array. Removal of tiles could be triggered by some host signal which actuates a release of the spring and pops the tile out of the array.

Serial connectivity can also be used in a close packed arrangement such as that illustrated in FIG. 43. It has the advantage that fewer connections have to be made and in practice it might be more reliable. However the net bandwidth between tiles will be less than a parallel system. Serial communication lends itself to optical and wireless systems thus removing the need for any physical connections. For optical technologies alignment of the transmitter and receiver is still important although the clever use of light pipes and lens capture techniques can introduce more flexibility. Wireless systems can use many different bands of the EM spectrum (kHz, MHz, GHz), utilizing a variety of modulation techniques (amplitude modulated, frequency

modulated, or those based on code division multiple access) and operate at a range of transmitter powers. There is no longer a need for direct alignment if the system is designed with suitable communication tolerances. The transmitter range plays a crucial part in the design. If there is only enough power in an emitted signal to be picked up within a few millimeters of a tile edge, then the signals will be isolated, the topology will be defined by the physical connectivity and the complexity of designing the system to avoid interference from neighboring signal sources will be minimized. However, an alternative design is to use more powerful radios. In this case all tiles will be able to contact all other tiles and inter-tile connectivity needs to be defined by another parameter. Signal strength can be used or, more deliberately, information that relates the ID of a tile to a spatial map (perhaps held in one master tile) describing the position of all tiles in the tile array. In this system it is also necessary to minimize inter-tile interference. For digital packetdata systems that operate at the same frequency, carrier sense multiple access (CSMA-CD or CSMA-CA) systems are well known techniques to solve this problem. Other solutions involve tiles using different frequencies, with frequencies reused depending on the power of the transmitters. This is the technique used by traditional cellular telephones. Yet another approach is to use Code Division Multiple Access (CDMA) that relies on the overlaying of signals in the same region of the EM spectrum, a technique known as spread spectrum modulation.

For loose packed display tiles, the wireless techniques described above in connection with close packed tiling generally become essential to the implementation. However, a special case of loose packing exists in which each edge of a tile does make contact with every other surrounding tile, except that it may only be a single point of contact and not at an accurately defined place. A wired version of this system can be built in which the entire edge of each tile is a serial connection including one of the two Vertices that define the edge. Communication in each direction can be achieved by a variety of commercially available techniques, including use of a one-wire interface (plus a ground) for bidirection communication between tags and a reader. Note that the ground connection for a tile arrangement can be derived by sharing a common ground connection through the surface the tiles are laid out on. For example, the surface could be made of a metal sheet. The system may be further enhanced by ensuring that the edge contact is made of a magnetic material and the vertices have a magnet embedded in the end. Such an arrangement ensures that there will be a good electrical contact between the transmitter and the receiver.

The receiver can also derive power from an electrically transmitted signal by bridge-rectifying it and storing the collected charge in a capacitor for use by its own electronics. Thus, power distribution can also be included in a one-wire interface. In this way flexible connectivity can be achieved to support the rapid and convenient rearrangement of tiles in which only the minimum amount of care needs to be taken in setting up connectivity.

Loosely packed tile displays such as illustrated in FIG. 45 may require that the display surfaces use a best effort algorithm to present a unified display with all the sections of the displayed image bearing the correct spatial arrangement to each other even though, in the case of rectangular tiles, they might not be registered vertically or horizontally and have an offset angle relative to each other. In order to implement the desired tile display algorithm, not only is the relative arrangement of tiles important but the exact offset (distance and angle) from each other is also important. There

are several methods that are suitable for automatically determining offsets between loosely packed tiles. For example, as illustrated with respect to FIG. 46 (showing communicating tiles 652 and 654, with respective displays 651 and 653), optical encoding 660 along an edge can be used to identify tile orientation. It is possible to use a binary coded optical pattern along an edge which is regular and encodes the distance from a vertex at any point. A tile that abuts, or is relatively aligned, can read this pattern using optical sensors 658 and 659 and determine the display offset in the direction of the edge. Alternatively, as illustrated by FIG. 47 (showing communicating tiles 672 and 674), it is possible to use radio based techniques that rely on signal strength triangulation. Each vertex 675 or 676 of a tile 672 can contain a wireless transmitter and a receiver. If these vertices transmit a short characteristic wireless signal at well known times, a nearby tile 674 can use the receivers situated at its own vertices 680, 681, 682, and 683 to triangulate the position of each transmitting vertex relative to them by measuring the relative delay by which the signal was received. After two of the vertices of the original transmitting tile 672 have signaled, the adjoining tile 674 can determine its exact position and orientation within their local region of a tile array. The transmitting and receiving tiles can now swap roles, with the result that both tiles will know their relative position. This process can be extended across the tile array.

Free format tiling differs from loose-packed tiling in that there are no proximity, or regular format, constraints. To demonstrate how a free format tiling system might work, the following example is described. Imagine a number of laptop computers each fitted with a Global Positioning System (GPS) and a radio modem. Each laptop can determine its position (with acceptable error) and communicate it to all the other laptops by contacting them through the radio modem. After some period of time the laptops will all know their relative location and absolute location. If any computer changes its location, it can update the local neighbors to ensure there is enough understanding in the array to consider the computers are in a known tiling configuration even though they are not close to each other and in fact they may be in different geographic regions. An application that might use this free format tiling system is one that wishes to ensure information is being correctly sent in a uniform and dispersed fashion across a very large area. For example, the information that each laptop computer receives could be instructions to release an amount of a pesticide used to control an insect that does damage to commercial crops. If the pesticide is released in too high a concentration in any locality, it may be hazardous to human health. The tiled approach allows the computers to roam (e.g. in the back of a truck), displaying information as to the type and concentration of pesticide that is to be released given their current relative proximity.

Various conventional algorithms can be used to support distribution of information between autonomous tiled displays. These algorithms assume a system by which there is a master controller generating data to be displayed. There is also a large array of tiled computers that the system will use to display visual data and/or process information. Each computer in the tiled array contains a unique ID. It is the job of the master to split the data into pieces that each computer can display and for this information to be packaged along with the ID of the target computer. The algorithms below describe how the information travels from the master to a destination display tile:

Daisy Chain Routing

Display tiles are arranged to have a logical connectivity with each other so that each one only transmits information to the next in a predefined line. The computers are said to be daisy chained to each. Any information sent to the start of the chain contains an ID and the first computer in the chain compares it to its own ID. If it matches, it acts on the data. If not, it sends the data on to the next computer in the chain until it finds its destination.

N-ary Routing

In N-ary routing the path to the destination is contained in the ID of the device. A simple routing example is schematically illustrated with reference to the direction arrows 695 in FIG. 48, which shows quaternary routing in physically connected tileable displays. In quaternary routing, an array is conceptually arranged as a quaternary tree with each node having an input and three outputs. In this system each pair of bits of the ID contains a routing command. A 0 indicates send the packet to the first output, a 1 indicates the second output, a 2 indicates the third output, and 3 indicates no further transmission. There is also a count that gets decremented by each node to tell successive nodes the bit number that is currently being considered and when the packet has reached its destination. In this way packets are forwarded from node to node with a simple choice at each stage until they reach their target display. As will be appreciated, it is possible to design N-ary systems with more than three outputs (a power of two is usually convenient for implementation (e.g. 4, 8, 16 . . .)).

Flooding

Flooding has no predefined routing structure. The computer that takes the first packet from the master checks to see if it has the correct ID. If not, the packet is sent out on all links to which it has not yet sent or received that packet. The result is a flood of copies of the packet across the array eventually reaching its destination. The packets must also have a maximum hop count to ensure they eventually are removed from the system. The disadvantage of this approach is that many more tiles are burdened with the processing of unwanted data than in the previous two schemes, which may impact the overall efficiency of the system.

Hot Potato

The Hot Potato algorithm is similar to the Flooding algorithm, except a retransmitted packet is sent out on only one output that is either chosen randomly or is the least busy. The process stops when the packet reaches the correct tile. The time that a packet takes to reach its destination is not deterministic.

As those skilled in the art will appreciate, other various modifications, extensions, and changes to the foregoing disclosed embodiments of the present invention are contemplated to be within the scope and spirit of the invention as defined in the following claims.

The claimed invention is:

1. A plurality of tileable devices for transferring data, comprising

- a first device having a display, a processor, and a first communication module for transferring data;
 - a second device having a display, a processor and a second communication module for transferring data;
 - a third device having a display, a processor and a third communication module for transferring data;
- wherein the first device is connected in substantially simultaneous communication with the second device and the third device to pass data based on spatial positions of the respective first device, second device, and third device, and

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the first device maintains information about spatial position of the second device and the third device, and transfers differing data to the second device and the third device based on that maintained spatial position information, wherein the spatial position information maintained by the first device includes, for each of the second and third devices, information defining a relative spatial position between that second or third device and the first device.

2. The plurality of tileable devices of claim 1, wherein the first, second and third communication modules respectively support optical data links.

3. The plurality of tileable devices of claim 1, wherein the first, second and third communication modules respectively support radio links.

4. The plurality of tileable devices of claim 1, wherein the first, second and third communication modules respectively support physical electrical connections.

5. The plurality of tileable devices of claim 1, each first, second and third device respectively further comprising a first, second, and third deformable piece, with intercommunication between at least two of the devices being triggered by a touching action between devices.

6. The plurality of tileable devices of claim 1, each first, second and third device respectively further comprising a first, second, and third deformable piece, with intercommunication between at least two of the devices being triggered by a stacking action between devices.

7. The plurality of tileable devices of claim 1, each first, second and third device respectively further comprising a first, second, and third deformable piece, with intercommunication between at least two of the devices being triggered by a tiling action between devices.

8. A plurality of tileable devices for transferring data comprising

a first device having a display, a processor and a first communication module for transferring data,

a second device having a display, a processor and a second communication module for transferring data,

a third device having a display, a processor and a third communication module for transferring data,

wherein the first device is maintained in at least intermittent communication with the second device, with the first device maintaining information about spatial position of the second device and the third device, and transferring differing data to the second device and the third device based on that maintained spatial position information, and the second device maintaining information about spatial position of the third device, and with the first device implementing a first data set, a second data set being transferred from the first device to the second device for implementation, and a third data set being transferred from the second device to the third device for implementation, wherein the spatial position information maintained by the first device includes, for each of the second and third devices, information defining a relative spatial position between the second or third device and the first device, and the spatial position information maintained by the second device including information defining a relative spatial position between the third device and the second device.

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9. The plurality of tileable devices of claim 7, wherein the first, second and third communication modules respectively support optical data links.

10. The plurality of tileable devices of claim 8, wherein the first, second and third communication modules respectively support radio links.

11. The plurality of tileable devices of claim 8, wherein the first, second and third communication modules respectively support physical electrical connections.

12. The plurality of tileable devices of claim 8, wherein the first, second and third device respectively further comprising a first, second, and third deformable piece, with intercommunication between at least two of the devices being triggered by a touching action between devices.

13. The plurality of tileable devices of claim 8, each first, second and third device respectively further comprising a first, second, and third deformable piece, with intercommunication between at least two of the devices being triggered by a stacking action between devices.

14. The plurality of tileable devices of claim 8, each first, second and third device respectively further comprising a first, second, and third deformable piece, with intercommunication between at least two of the devices being triggered by a tiling action between devices.

15. A dynamic array of devices, the array comprising, a plurality of devices, each device having a display maintainable in a user determined relationship to each other, and each device having a determinable information state, and

a plurality of position detectors, each device having at least one of the plurality of position detectors usable to determine its position relative to one or more of the plurality of devices, wherein in response to each device determining its relative position, that device transmits the determined relative position to at least one other device,

wherein determinable information state of each of the plurality of devices is modified upon its change of position relative to one or more devices.

16. A tileable display system, comprising

a first device having a display, a processor, and a first communication module for transferring data,

a second device having a display, a processor and a second communication module for transferring data, wherein:

the first device is connected in substantially simultaneous communication with the second device to pass data based on spatial positions of the respective first device and second device, and

the first device maintains information about spatial position of the second device, and selectively transfers data to the second device based on the maintained spatial position information, wherein the spatial position information includes information defining a relative spatial position between the first and second devices.

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